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CAST ALUMINUM STRUCTURES TECHNOLOGY (CAST) STRUCTURAL TEST AND EVALUATION (PHASE V) PART I—FULL SCALE TEST

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Seattle, Washington 98124

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Technical Report AFWAL-TR-80-3021, Part I
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Full Scale tests were conducted on the cast A357-T6 aluminum alloy bulkheads developed and manufactured for the Cast Aluminum Structures Technology (CAST) program. One test article was subjected to four lifetimes of durability and damage tolerance testing and a second was subjected to additional two lives of damage tolerance testing including residual strength tests to and exceeding ultimate loads. The full scale test program successfully demonstrated that the static strength, durability, and damage tolerance requirements for the bulkhead were met.

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FOREWORD

This report was prepared by the Boeing Military Airplane Company, Advanced Aircraft Branch, Seattle, Washington under USAF Contract No. F33615-76-C-3111. The contract work was performed under project 486U under the direction of the Flight Dynamics Laboratory, Advanced Metallic Structures/Advanced Development Program Office, Wright-Patterson AFB, Ohio. A significant portion of the contract was funded by the Metals Branch of the Manufacturing Technology Division of the Materials Laboratory. The Air Force Project Engineer was John R. Williamson of the AMS Program Office, Structural Mechanics Division, Flight Dynamics Laboratories (AFWAL/FIBAA).

The Boeing Military Airplane Company was the contractor, with Donald E. Strand as Program Manager and Donald D. Goehler as Technical Leader. Work covered by this report was conducted by Christian K. Gunther; the Air Force test engineer was Don Brammer.

This report is Part I of a three-part report on Phase V activities. The contractor's report number is D180-25724-1. The report covers work from February 1977 through January 1980. Other work performed on the CAST program is reported in:

- AFFDL-TR-77-36 Final Report (Phase I) for period June 1976—February 1977
- AFFDL-TR-78-62 Final Report (Phase II) for period June 1976—March 1978
- AFFDL-TR-78-7 Final Report (Phase III) for period February 1977—December 1977
- AFFDL-TR-79-3029 Final Report (Phase IV) for period June 1977—March 1979

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INTRODUCTION

The objective of Phase V of the CAST program was to demonstrate the structural integrity of the cast bulkhead by full-scale test.

During Phase III, Detail Design, the bulkhead was analyzed for static strength, durability, and damage tolerance. Margins of safety were demonstrated for all critical conditions. The demonstration of static strength, durability, and damage tolerance by full-scale test provides a check of the analysis and identifies critical areas of the airframe not previously identified by analysis or component testing. A successful demonstration of structural integrity by a full-scale test provides a high degree of confidence that the component will function satisfactorily in its intended service environment.

SECTION II
SCOPE OF FULL-SCALE TEST PROGRAM

The test program consisted of full-scale testing of two cast aluminum bulkheads. The test articles were installed in the test fixture consecutively and testing was conducted in the following manner:

Test Article I (Boeing Bulkhead M07)
- Durability Test Program
- Damage Tolerance Test Program I

Test Article II (Boeing Bulkhead M04)
- Damage Tolerance Test Program II

The following briefly summarizes each portion of the full-scale test program:

- The Durability Test Program consisted of applying spectrum load blocks made up of repeated flight-by-flight loads resulting from the AMST design mission profile mix to Test Article I. Spectrum load blocks corresponding to the usage of four design service lives were applied.
- Damage Tolerance Test Program I was conducted concurrently with the last two lives of durability testing on Test Article I and consisted of crack growth and residual strength testing. Initial flaws were implanted prior to the third lifetime of durability testing.
- Damage Tolerance Test Program II was conducted on Test Article II to generate additional data. It consisted of two lifetimes of cyclic loading with initial damage and of residual strength testing of the thus fatigue-damaged bulkhead.

SECTION III
FULL-SCALE TEST SETUP

1. TEST ARTICLE

The test article is the station 170 bulkhead of the YC-14 fuselage, shown in Figure 1. The bulkhead is approximately 7-1/2 x 4-1/2 feet in size and is made of A357 cast aluminum alloy. The bulkhead is a monolithic structure consisting of a corrugated pressure web from the upper horizontal tee-section cross-member (WL 130) to the top of the bulkhead (WL 150). The lower bulkhead section consists of a thin web stiffened by vertical and horizontal supports.

The bulkhead serves a dual purpose: first, it is the backup structure for the nose landing gear; second, the upper portion serves as a pressure bulkhead. The nose gear trunnion is attached to the bulkhead at four clevises by means of two yoke fittings.

2. TEST FIXTURES AND LOAD APPLICATION SYSTEM

The test fixture and test setup were designed to provide as realistic and efficient a means as possible for all bulkhead testing. The test setup was installed in Building 65 at Wright-Patterson AFB (Figure 2). The test article was attached to a transition structure that simulated the surrounding fuselage.

The test article, including transition structure, was supported at station 230 and cantilevered from A-frames. Doublers were added to the skin of the transition structure forward from station 230 to allow transition of skin loads into a structural supporting ring. The supporting ring provided the attachment of a pressure bulkhead that transmitted applied loads to the supporting A-frames.

The test loads were applied by hydraulic actuators through a simulated landing gear trunnion support structure (Fig. 3). The vertical loads were applied by two actuators and reacted into the structural floor beams of the test facility. The side loads were applied by tension actuators on either side of the trunnion support structure. The fore and aft loads were applied by two actuators and were reacted at the supporting A-frames (Fig. 4). The test fixture and setup

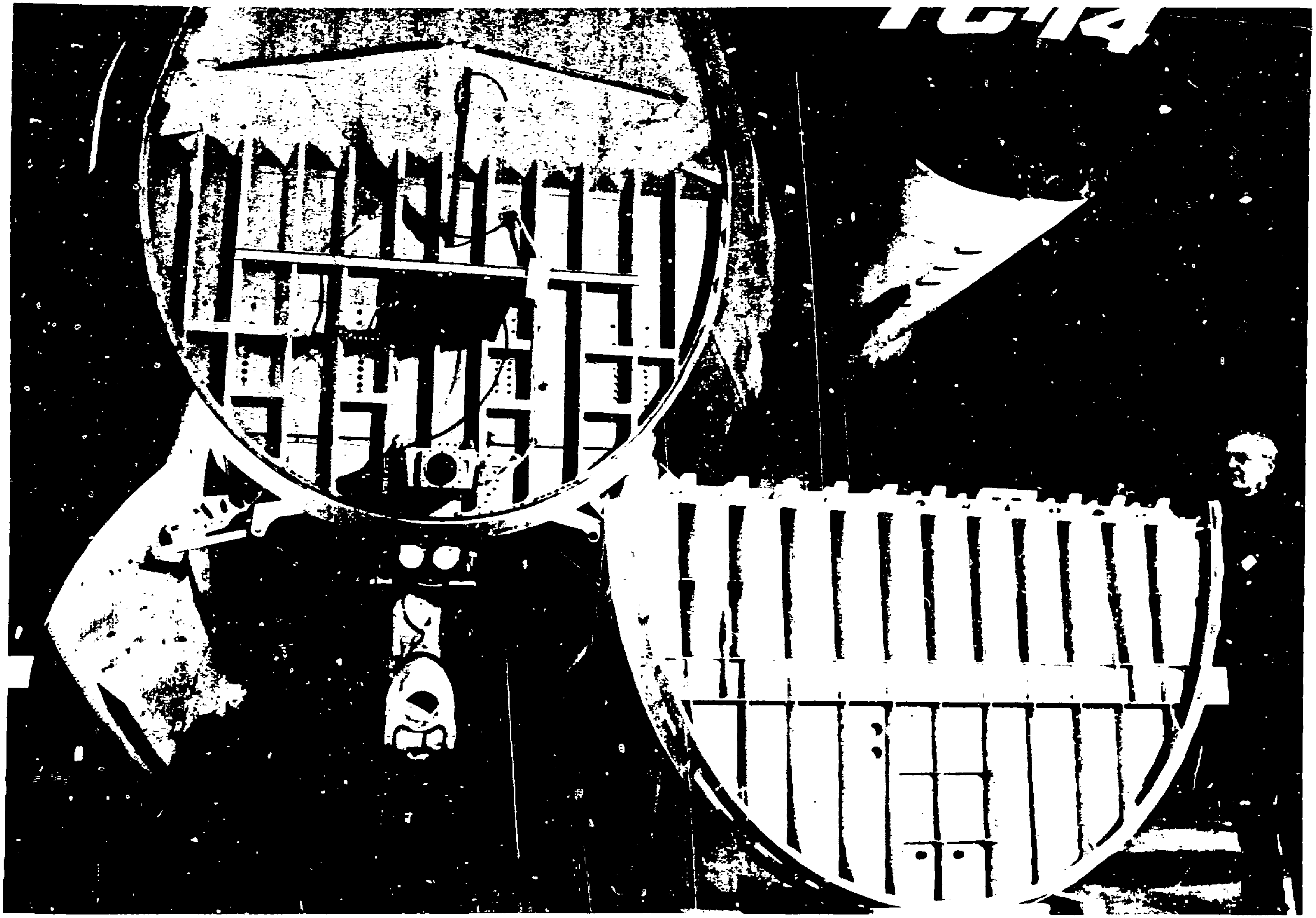


Figure 1. Cast Aluminum Bulkhead For YC-14

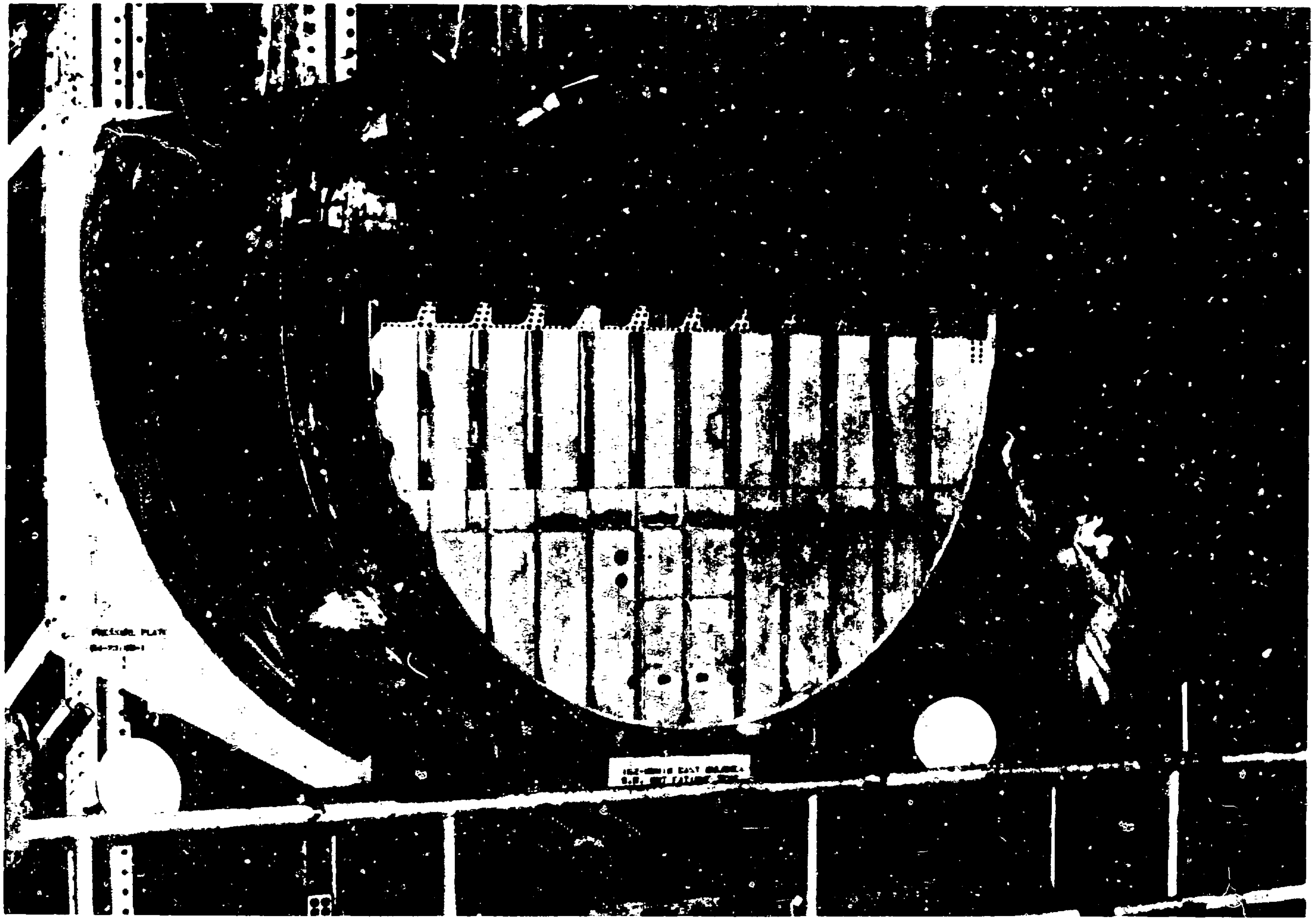


Figure 2. Full-scale Test Setup at Wright-Patterson AFB

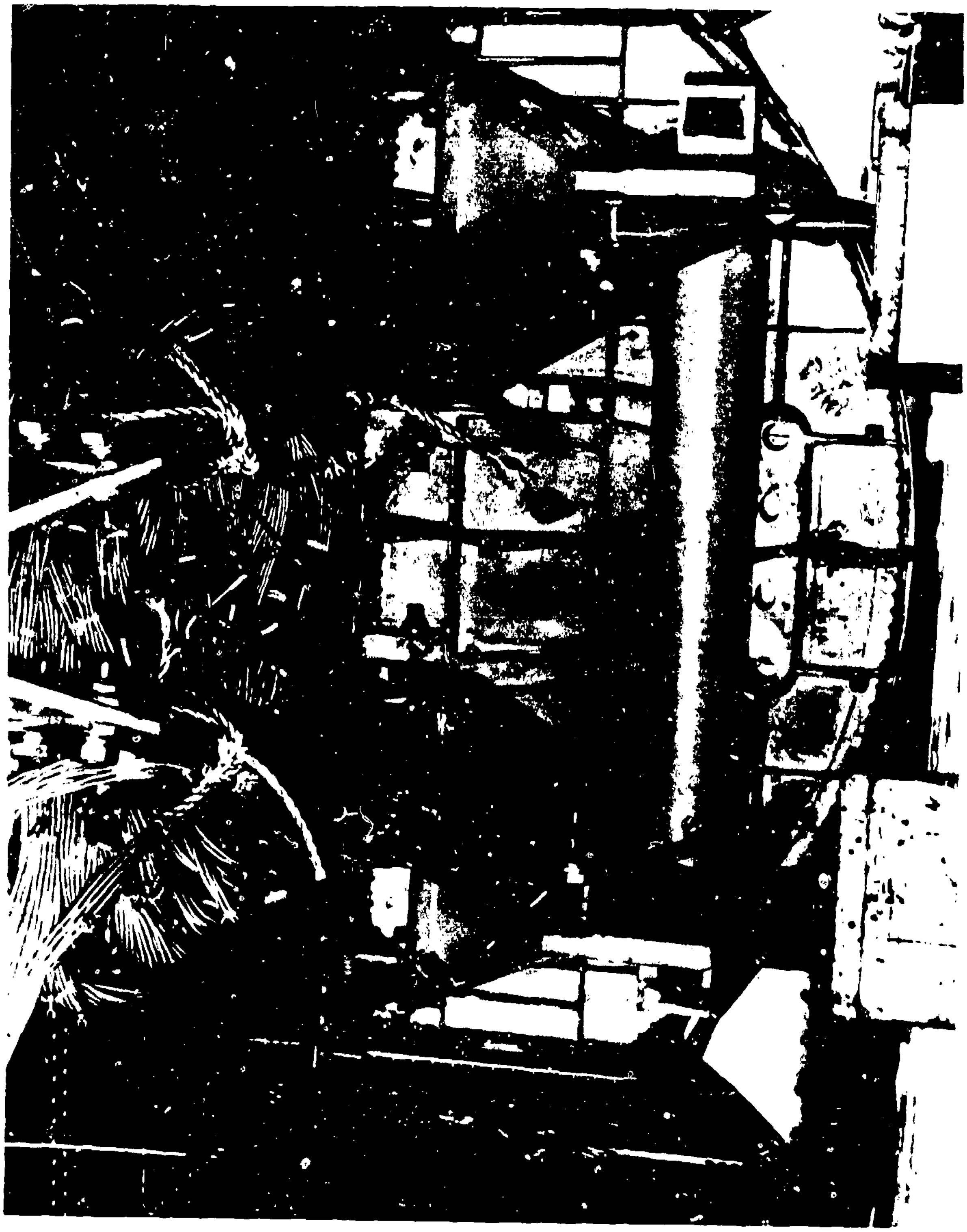


Figure 3. Nose Gear Load Fixture

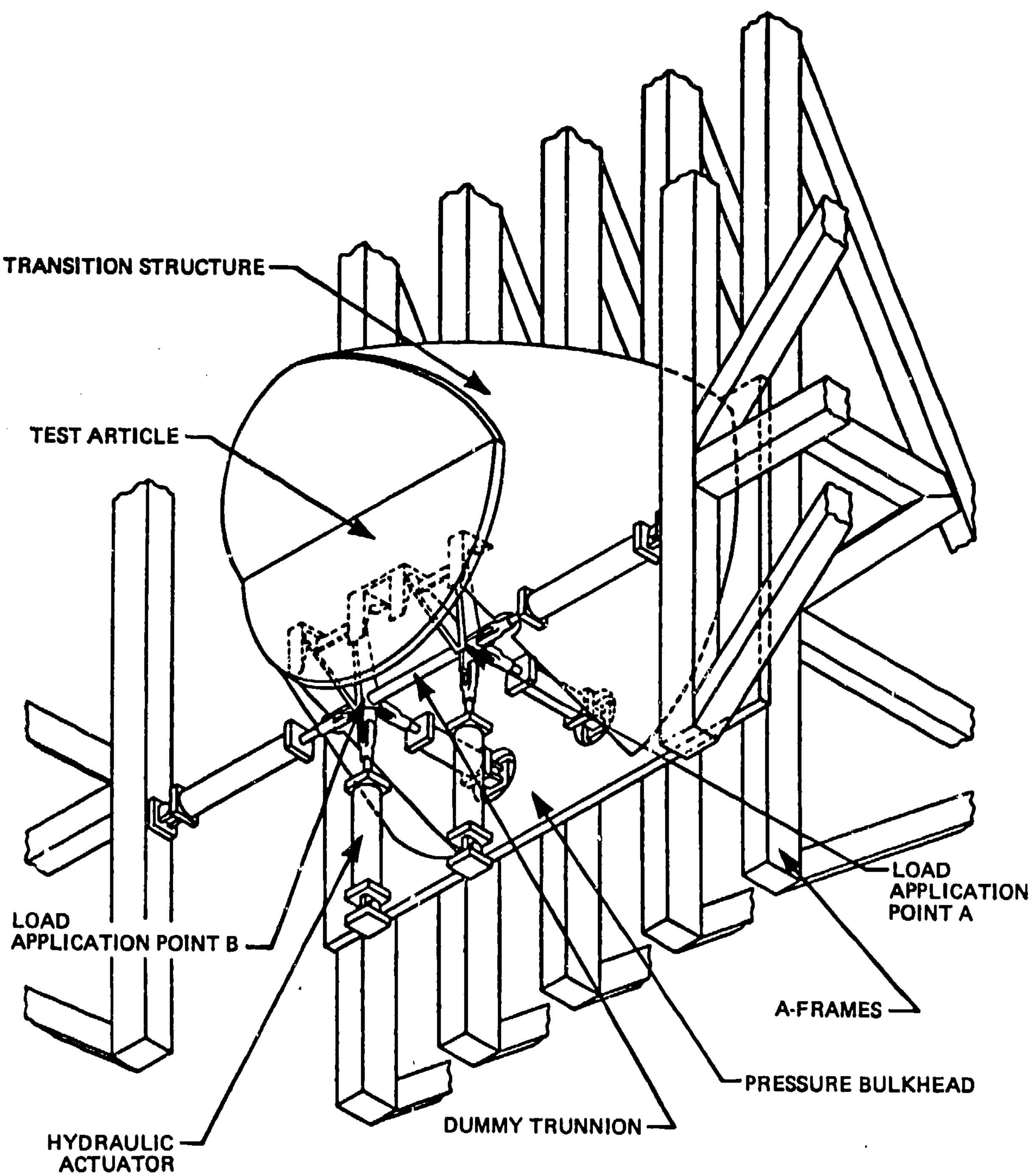


Figure 4. Schematic of Full-scale Test Setup

were identical for both the durability and damage tolerance test (I) and damage tolerance test II.

The test system used in this program is represented schematically in Figure 5. It is an integrated system using a minicomputer for appropriate load function generation and a typical electrohydraulic load control system for test load application. An independent minicomputer verifies the load function generation as it is generated, and a supervisory computer controls a third minicomputer in the acquisition, processing, monitoring, recording, and displaying of structural response data (strain, load, deflection, and pressure). In addition, a redundant load monitor system is used to ensure proper load introduction to the test article.

3. INSTRUMENTATION

Instrumentation was provided to determine stress distributions for verification of the stress analysis, to demonstrate the adequacy of the test setup, and to provide data to preclude premature structural failure. The instrumentation included the following:

- Load Cells—Strain-gage-type load cells were used for load monitoring and control.
- Strain Gages—Bonded resistance strain gages were used to record strain data. Both single-element axial and three-element rosettes were used.
- Deflection Indicators—Electrical deflection indicators were used to measure the displacements of the test structure.
- Crack Detectors—Crack wire circuits were installed around the pin holes to detect flaw growth from the holes.
- Pressure Transducers—Pressure transducers were used to control, monitor, and record the air pressure in the upper portion of the test structure.

4. TEST LOADS

The repeated loads, which are the result of the design usage of the AMST aircraft, were applied for durability and damage tolerance testing in accordance with MIL-A-008866B (USAF). The design usage is represented by a mission mix consisting of blocks of missions made up of five different flights (Table 1).

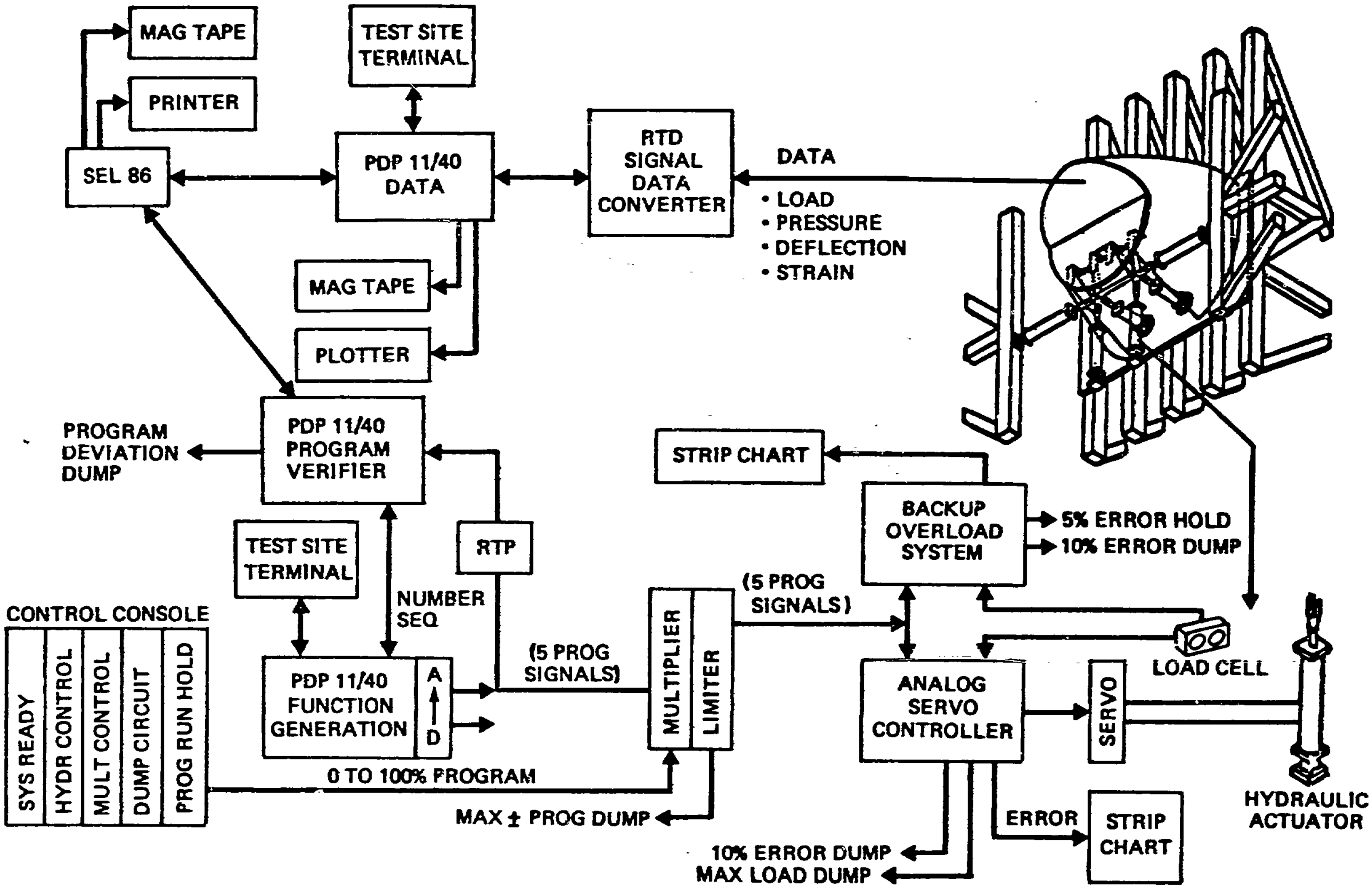


Figure 5. Test System Schematic

The usage corresponding to one design service life (25,000 hours) is represented by the application of 1,516 load blocks. The repeated loads consist of nose-gear loads and pressurization. The nose-gear loads are caused by aircraft taxi, takeoff roll, landing impact, and landing roll. Air pressure acts on the upper portion of the bulkhead during flight. Table 2 shows the breakdown of a flight into load segments. The landing loads vary according to the aircraft sinkrate distribution of MIL-A-008866 for conventional landings. The sinkrate distribution for STOL operations was obtained from computer-simulated landings. The correlation of aircraft sinkrates to nose-gear loads was established from flight test data. The repeated loads spectra are contained in the appendices. Appendix A presents the loads spectrum for the durability and damage tolerance (I) tests.

After completion of the Durability and Damage Tolerance (I) Tests (Section IV.3), an error was detected involving the sign convention for the external side loads on the nose gear. This error caused side loads A_L, B_L (see Appendix A) to be applied in the opposite direction. Thus, load conditions involving nose-gear side loads were not applied correctly. Appendix B contains the corrected load spectrum that was applied for damage tolerance test II. Pressure cycles were eliminated from this revised spectrum, since the durability and damage tolerance of the bulkhead subjected to pressure cycles had been fully demonstrated by the durability and damage tolerance (I) test.

The loads for static test (residual strength) were in accordance with MIL-A-008866A. The bulkhead was subjected to two load conditions (Table 3):

- Springback landing
- Boeing side-load landing

5. DATA ACQUISITION

During the test, data from six load cells, six deflection indicators, two pressure transducers, and 114 strain-gage channels were monitored and recorded. A Real-Time Peripheral (RTP) unit, amplified, digitized, and multiplexed the 128 channel outputs and provided a binary output. The RTP was controlled by a Digital Equipment Corporation PDP-11 minicomputer, through a Direct Memory Access (DMA) channel. The data blocks obtained were immediately passed on to

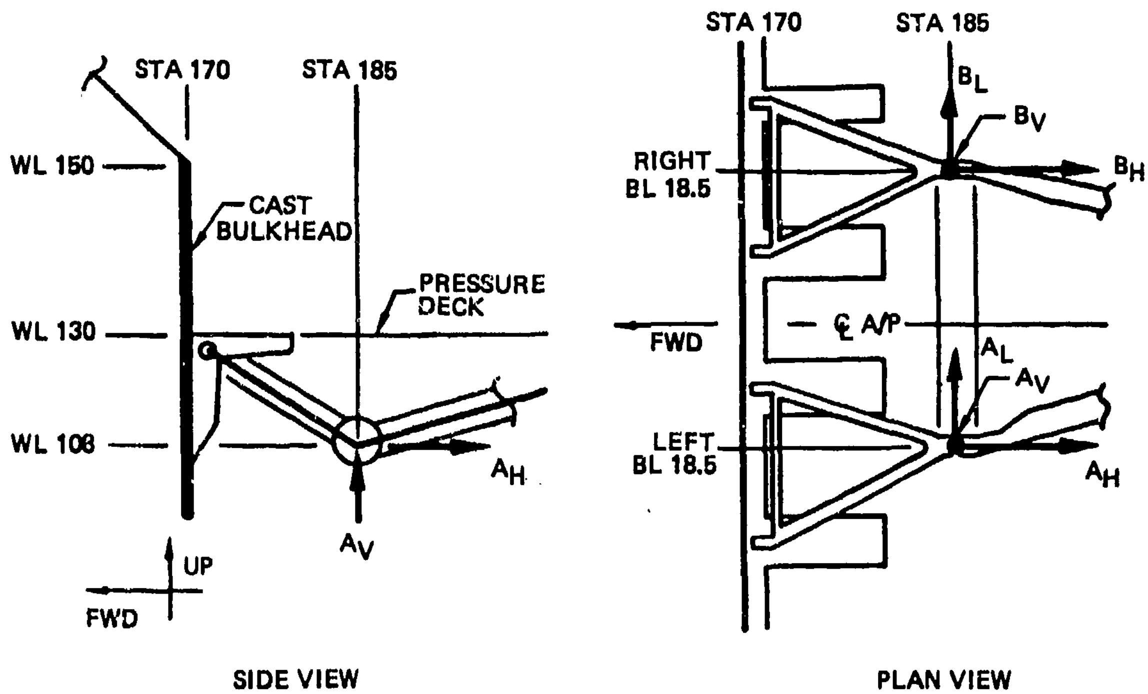
Table 1. AMST Design Mission Mix

FLIGHTS	TYPE OF FLIGHT	HOURS
1	LONG RANGE CTOL (TYPE 1)	5.0
4	LOW ALTITUDE RESUPPLY CTOL (TYPE 2)	0.5
3	LOW ALTITUDE RESUPPLY STOL (TYPE 3)	0.5
5	SHORT RANGE CTOL & TOUCH & GO (TYPE 4)	1.0
3	SHORT RANGE STOL & TOUCH & GO (TYPE 5)	1.0
16	TOTAL FLIGHT HOURS	16.5

Table 2. Typical Flight Segments

TAXI
PRESSURIZATION
LANDING
BRAKING
TURNING

Table 3. Ultimate Static Loads



FORCES POSITIVE AS SHOWN

STATIC-LOAD CONDITION	LOAD LOCATION					
	LEFT BL 18.5			RIGHT BL 18.5		
	A_H	A_L	A_V	B_H	B_L	B_V
SPRING BACK LANDING	-31.8	0	79.5	-22.6	0	56.9
BOEING SIDE LOAD LDG	-1.4	-45.0	98.9	-56.2	0	-79.4

LOADS IN kips

the Systems Engineering Laboratory (SEL) Systems 86 Digital Computer, where they were processed into engineering units for online displays and recorded on magnetic tape for offline processing.

An Imlac Computer System, consisting of a computer, graphic CRT display, and keyboard, was used to process and display (online) test data during the static tests. The ability to plot strain, deflection, and load as a function of percent limit load was available with the addition of a Varian Model 343 electrostatic plotter. During the durability and damage tolerance test, test data were monitored with a TEK CRT display. In conjunction with a PDP-11 minicomputer and tape drive, data were recorded at rates up to 20 samples per second per channel. Two 8-channel Hewlett-Packard Model 7418 chart recorders monitored loads, load controller error signals, and one program signal, providing continuous visual displays in analog form.

SECTION IV
FULL-SCALE TEST

1. PHOTOELASTIC COATING SURVEY

A photoelastic coating survey was conducted after completion of the test setup. The objective of the survey was (1) to study the general stress field, (2) to identify local stress concentrations, and (3) to determine optimum strain-gage locations. The bulkhead was covered with coating in the areas of interest, as shown in Figure 6. The load conditions identified in Table 4, and selected from the repeated loads spectrum, were applied to the bulkhead in increments of 20 percent of their maximum values. The coating was observed under polarized light. Points of interest were identified as "photostress points" (Fig. 7) and readings of fringes were recorded for these points at each load increment. Table 5 lists the readings at 100 percent load of the applied conditions. A qualitative analysis of the stress field was assumed sufficient for the purpose of the survey and, therefore, only an approximate conversion from fringes to magnitudes of stress is given in the table. The highest stress (16.7 ksi) observed in this manner occurred at photostress point (1) (Fig. 8).

Since this stress concentration was higher than desired, a generous radius was introduced into the stiffening web to relieve the high stress. No problems were encountered later during the test program at this area.

2. STRAIN SURVEY

A strain survey of the test setup, including the bulkhead, transition structure, and loading fixture, was conducted. Locations for strain gages on the bulkhead were determined based on the results of the photoelastic coating survey. Twenty-four rosettes and 18 axial gages were placed on the bulkhead (Fig. 9). Strain gages located on the transition structure and loading fixture had been installed at Boeing prior to delivery of the test article. The locations of these strain gages (Fig. 10) were determined from the results of the finite-element analysis conducted during Phase III of the CAST program. The load conditions applied for the strain survey were as shown in Table 6. The corresponding loads were applied in increments to check for linearity of the gage readings. Due to the

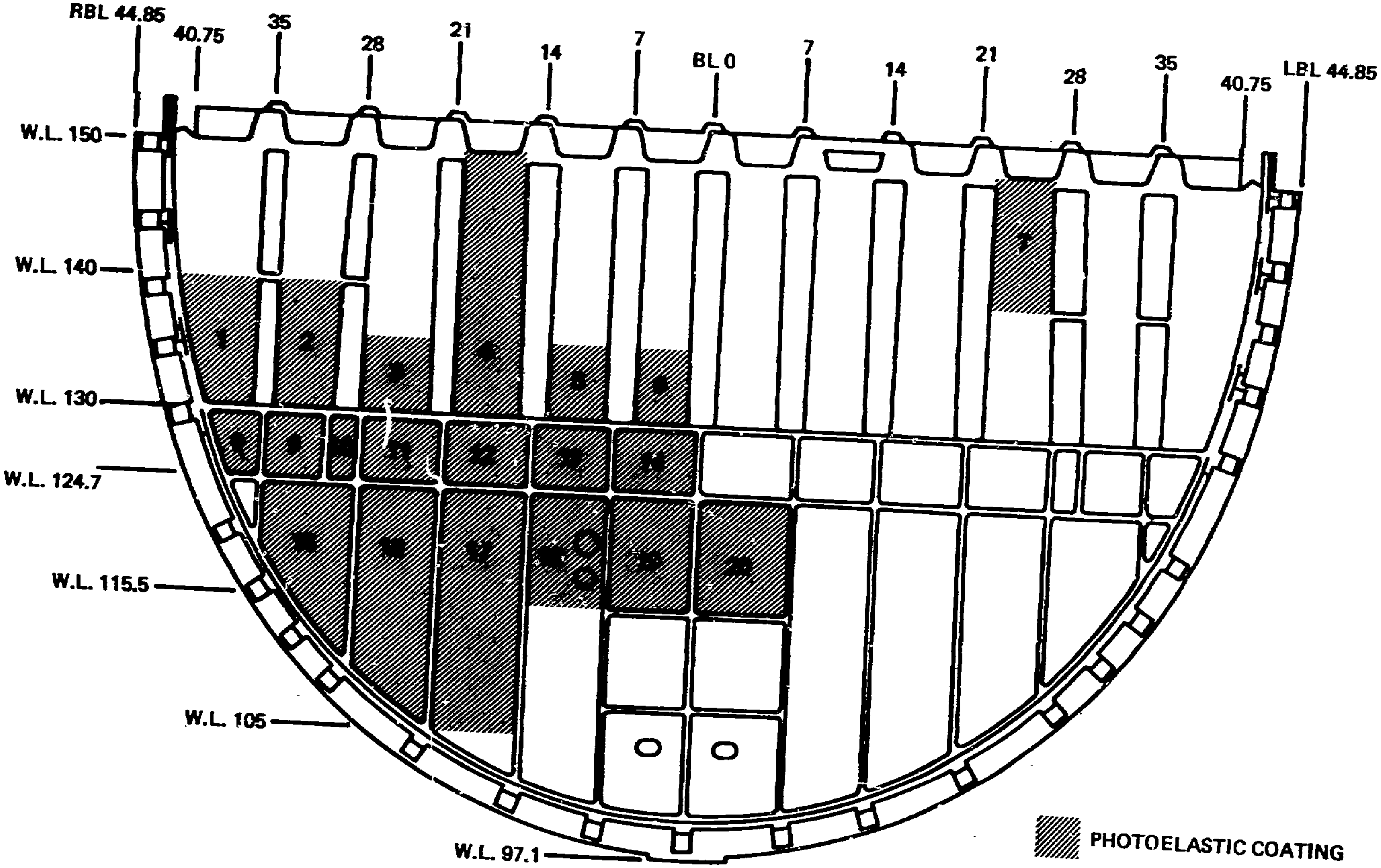


Figure 6. Areas of Photoelastic Coating Survey

Table 4. Load Conditions for Photoelastic Coating Survey

Condition	Desig.	Load in kips					
		A_V*	A_H*	A_L*	B_V*	B_H*	B_L*
Landing with side load	1 (LS9.2)** 2 (LS9.3)	48.5 -41.0	22.1 -62.2	0 -26.7	-41.0 48.5	-62.2 -22.1	26.7 0
Landing	3 (LS14.1)	-62.8	-87.6	0	-62.8	-87.6	0
Turning	4 (TL1) 5 (TR1)	21.1 -19.1	- 2.4 -20.4	0 -12.0	-19.1 21.1	-20.4 - 2.4	12.0 0
Steering	6 (SL1) 7 (SR1)	12.1 -12.1	5.4 - 5.4	0 - 7.2	-12.1 12.1	- 5.4 5.4	7.2 0

* See table 3 for location of forces and sign convention
** Load conditions per appendix A

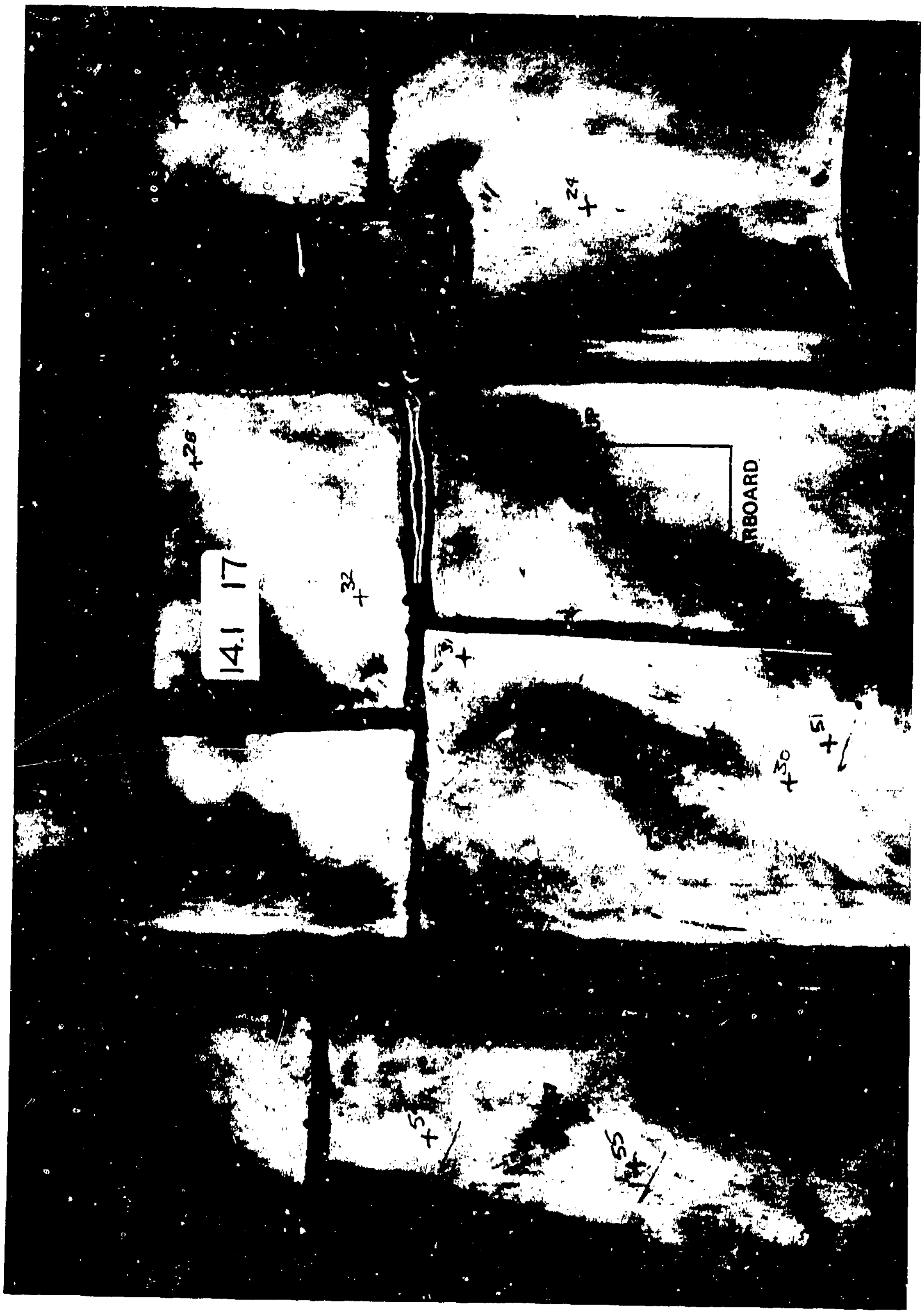


Figure 7. Typical Photostress Points

Table 5. Results of Photoelastic Coating Survey

Point no.	Condition 1		2		3		4		5		6		7		Location
	Div	ksi	Div	ksi	Div	ksi	Div	ksi	Div	ksi	Div	ksi	Div	ksi	
1	111	16.7	-		-		35	5.3	-		26	3.9	-		7
2	57	8.6	47	7.1	-		20	3.0	25	3.8	-		20	3.0	20
3	76	11.4	61	9.2	-		8	1.2	30	4.5	35	5.3	22	3.3	20
4	61	9.2	54	8.1	-		-		24	3.6	-		20	3.0	20
5	42	6.3	54	8.1	-		32	4.8	20	3.0	29	4.4	20	3.0	19
6	16	2.4	-		-		-		-		-		-		19
7	62	9.3	54	8.1	-		30	4.5	15	2.3	-		-		19
8	62	9.3	60	9.0	-		28	4.2	23	3.5	-		-		19
9	17	2.6	-		-		-		-		-		-		6
10	27	4.1	-		-		-		-		-		-		6
11	34	5.1	-		-		-		-		-		-		6
12	54	8.1	-		-		-		-		-		-		4
13	10	1.5	-		-		-		-		-		-		4
14	50	7.5	72	10.8	32	4.8	25	3.8	-		41	6.2	30	4.5	4
15	14	2.1	51	7.7	38	5.7	-		-		-		-		4
16	15	2.3	-		-		-		-		-		-		18
17	37	5.6	34	5.1	-		-		-		-		-		18
18	37	5.6	16	2.4	-		-		-		-		-		18
19	19	2.9	-		-		-		-		-		-		18
20	-		-		-		-		-		-		-		18
21	-		-		-		-		-		-		-		18
22	-		-		-		-		-		-		-		18
23	-		-		-		-		-		-		-		18
24	15	2.3	-		-		-		-		-		-		18
25	31	4.7	-		-		-		-		-		-		17

Table 5. Results of Photoelastic Coating Survey (Continued)

Point no.	Condition 1		2		3		4		5		6		7		Location
	Div	ksi	Div	ksi	Div	ksi	Div	ksi	Div	ksi	Div	ksi	Div	ksi	
26	27	4.1	24	3.6	-		-		-		-		-		17
27	32	4.8	-		-		-		-		-		-		17
28	40	6.0	-		-		-		-		-		-		17
29	28	4.2	-		-		-		-		-		-		17
30	-		-		-		-		-		-		-		17
31	31	4.7	-		-		-		-		-		-		17
32	40	6.0	-		-		-		-		-		-		17
33	-		-		-		-		-		-		-		16
34	-		17	2.6	-		-		-		-		-		16
35	-		-		-		-		-		-		-		16
36	-		-		-		-		-		-		-		16
37	-		-		-		-		-		-		-		16
38	-		-		36	5.4	-		-		-		-		16
39	23	3.5	-		-		-		-		-		-		5
40	-		10	1.5	14	2.1	-		-		18	2.7	-		7
41	-		35	5.3	-		-		-		-		-		20
42	-		65	9.8	-		-		-		-		-		19
43	-		52	7.8	-		-		-		-		-		18
44	-		47	7.1	-		-		-		-		-		18
45	-		20	3.0	-		-		-		-		-		18
46	-		25	3.8	-		-		-		-		-		18
47	-		34	5.1	-		-		18	2.7	-		-		18
48	-		28	4.2	-		-		-		-		-		17
49	-		19	2.9	-		-		-		-		-		17
50	-		27	4.1	-		-		-		-		-		17
51	-		55	8.3	44	6.6	-		-		-		-		17
52	-		55	8.3	41	6.2	-		-		-		-		17

Table 5. Results of Photoelastic Coating Survey (Concluded)

Point no.	Condition 1 Div	1 ksi	2 Div	2 ksi	3 Div	3 ksi	4 Div	4 ksi	5 Div	5 ksi	6 Div	6 ksi	7 Div	7 ksi	Location
53	-		34	5.1	-		-		-		-		-		16
54	-		50	7.5	41	6.2	-		31	4.7	-		-		16
55	-		60	9.0	33	5.0	-		-		-		-		16
56	-		40	6.0	52	7.8	-		-		-		-		15
57	-		44	6.6	47	7.1	-		26	3.9	-		-		15
58	-		42	6.3	-		-		-		-		-		15
59	-		67	10.1	-		-		24	3.6	-		-		9
60	-		59	8.9	-		-		-		-		-		9
61	-		70	10.5	48	7.2	-		24	3.6	18	2.7	20	3.0	1
62	-		64	9.6	-		-		-		-		-		2
63	-		68	10.2	-		-		-		-		-		13
64	-		84	12.6	-		-		-		-		-		5
65	-		62	9.3	-		-		39	5.9	-		31	4.7	18
66	-		31	4.7	-		-		-		-		-		13
67	-		40	6.0	-		-		-		-		-		2
68	-		71	10.7	22	3.3	-		-		30	4.5	32	4.8	2
69	-		71	10.7	-		-		29	4.4	-		29	4.4	5
70	-		-		24	3.6	-		-		-		-		7
71	-		-		-		-		-		-		-		
72	-		-		-		-		-		-		-		
73	-		-		-		-		-		-		-		
74	-		-		48	7.2	-		-		-		-		9
75	-		-		-		-		-		-		-		

Figure 8. Stress Concentration at Photo Stress Point 1

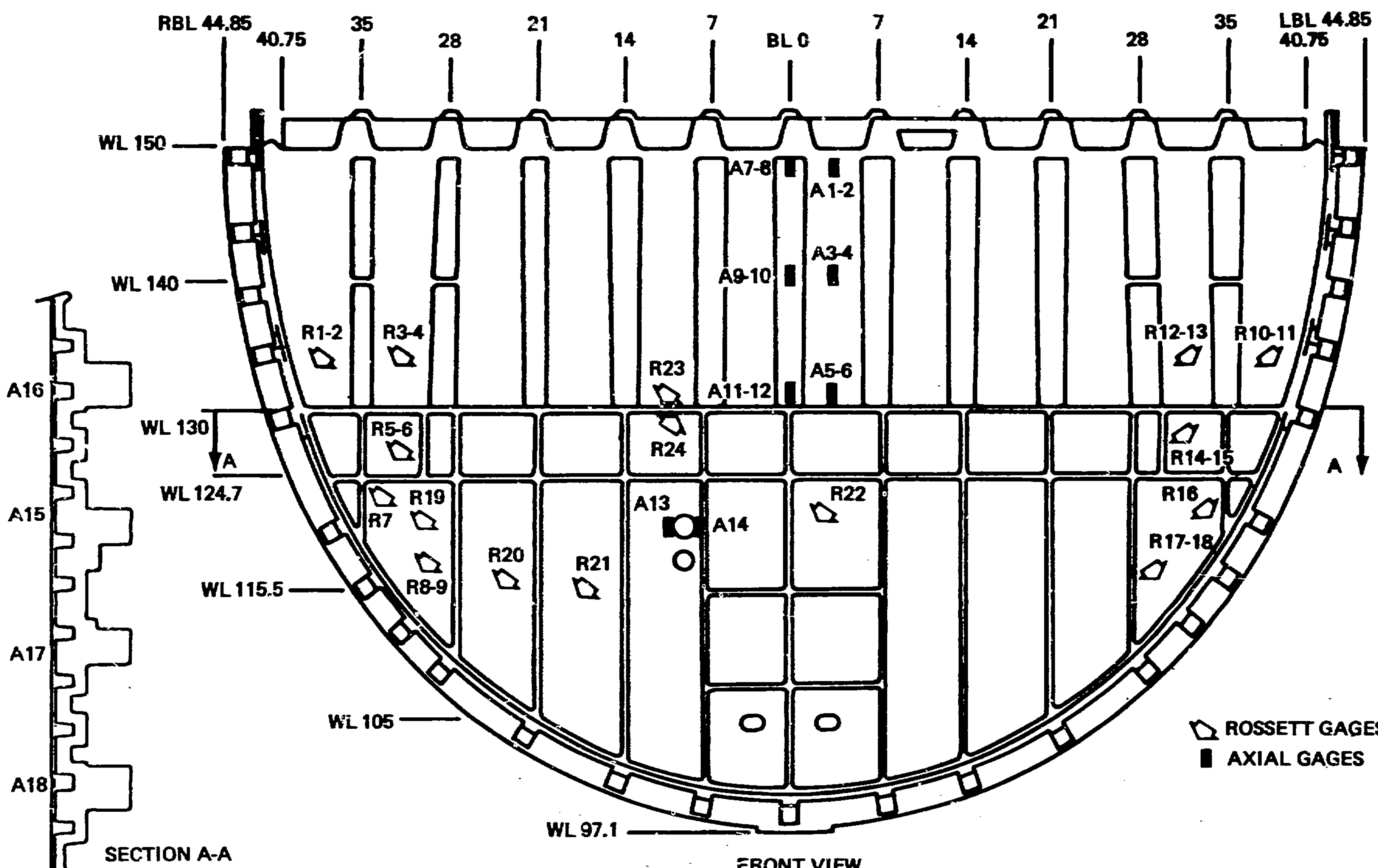


Figure 9. Strain Gage Locations on Test Article I

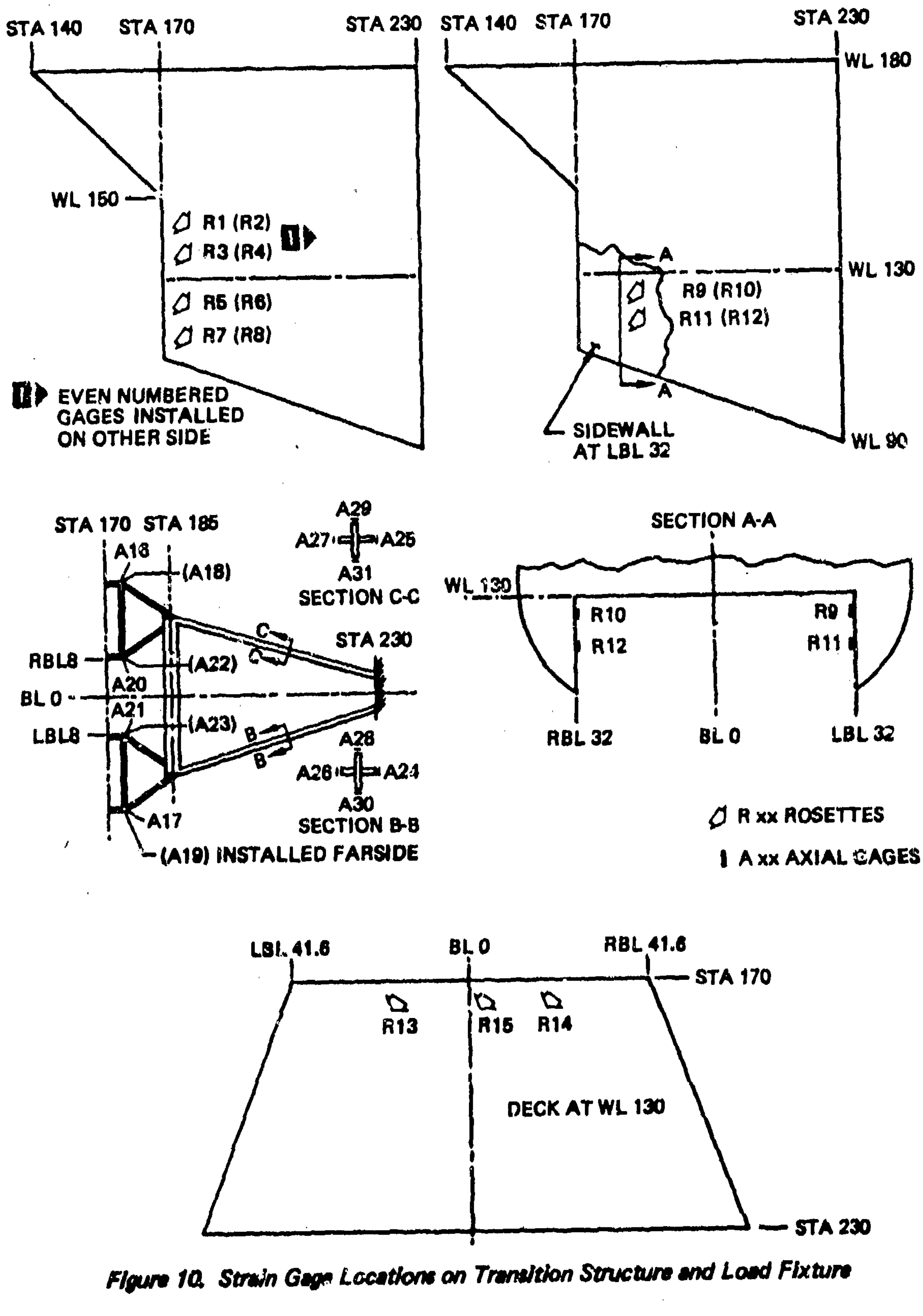


Figure 10. Strain Gage Locations on Transition Structure and Load Fixture

Table 6. Load Conditions for Strain Survey

Condition	Description	A_V	A_H	A_L	B_V	B_H	B_L
1	100 kips vert.	4.2	-47.4	0	4.2	-47.4	0
2	10 kips horiz.	- 7.2	- 2.5	0	- 7.2	- 2.5	0
3	6 kips side	10.1	4.5	0	-10.1	- 4.5	6.0
4	LS 9.2 *	48.5	-22.1	0	-41.0	-62.2	26.7
5	LS 9.3 *	-41.0	-62.2	-26.7	48.5	-22.1	0

See Table 3 for location of forces and sign convention, loads in kips.
* Load conditions per Appendix A

relatively low magnitude of the stresses, a certain amount of scatter in the data appeared to be unavoidable. Figures 11 through 15 show recorded stresses at 100 percent load in comparison to the predicted stresses from the finite-element analysis. Good correlation was found for the symmetric conditions, while the correlation for the asymmetric conditions was not as good. The local perturbations of the stress field caused by out-of-plane displacements of the buckled shear webs contributed to the poorer correlation. The shear webs had buckled permanently when the bulkhead was quenched in water after solution heat treatment. Considering this and the relatively low magnitude of the stresses, the results obtained were considered adequate.

3. DURABILITY AND DAMAGE TOLERANCE (I) TESTS

A thorough inspection of the bulkhead was conducted prior to the start of cyclic loading for the durability test. This and prior inspections indicated that a number of processing defects existed in the casting. The quench cracks (Fig. 16) were considered to be the most severe preexisting defects on the bulkhead. A crack growth analysis of an assumed idealized crack at this location, however, indicated that the bulkhead should be able to withstand the service loads for the duration of the durability test without any significant crack growth initiating from these quench cracks.

Load cycling was begun in December 1978. The loads applied were as described in Section III.4 (see also Appendix A). Inspections in different levels of intensity were conducted at regular intervals. They are briefly described below:

- Category I—Walkaround visual examination conducted daily.
- Category II—Inspection of critical areas in addition to Category I inspection. Comparison of most recent test data with baseline data, conducted every 1/8 life.
- Category III—Consists of Category I and II inspections and additional NDI, including penetrant and ultrasonic inspections and X-radiography, conducted every 1/4 life.
- Category IV—Consists of Category I and II inspections and an expanded Category III inspection. Conducted at completion of each service life of testing.

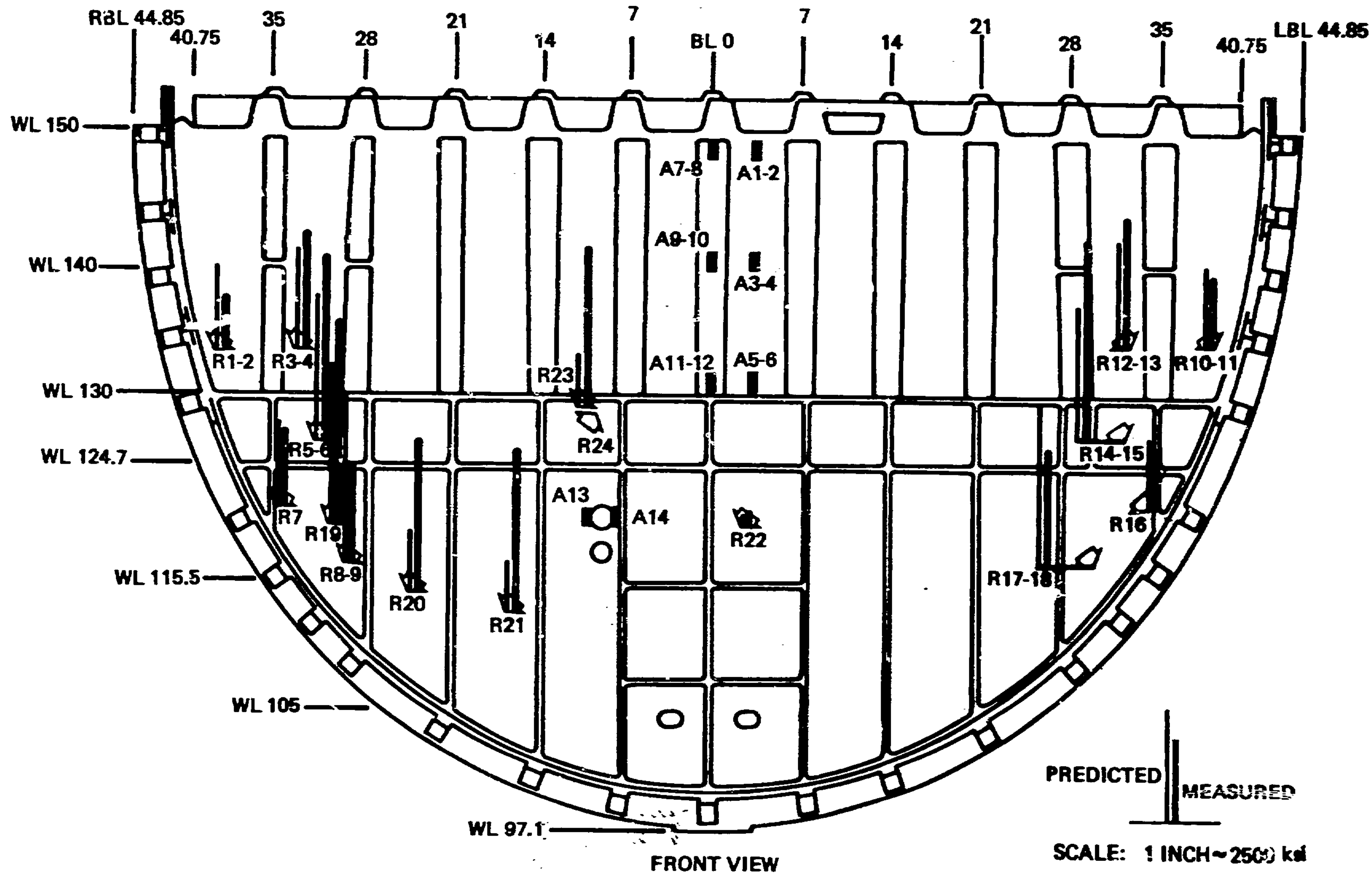


Figure 11. Results of Strain Gage Survey, Condition 1

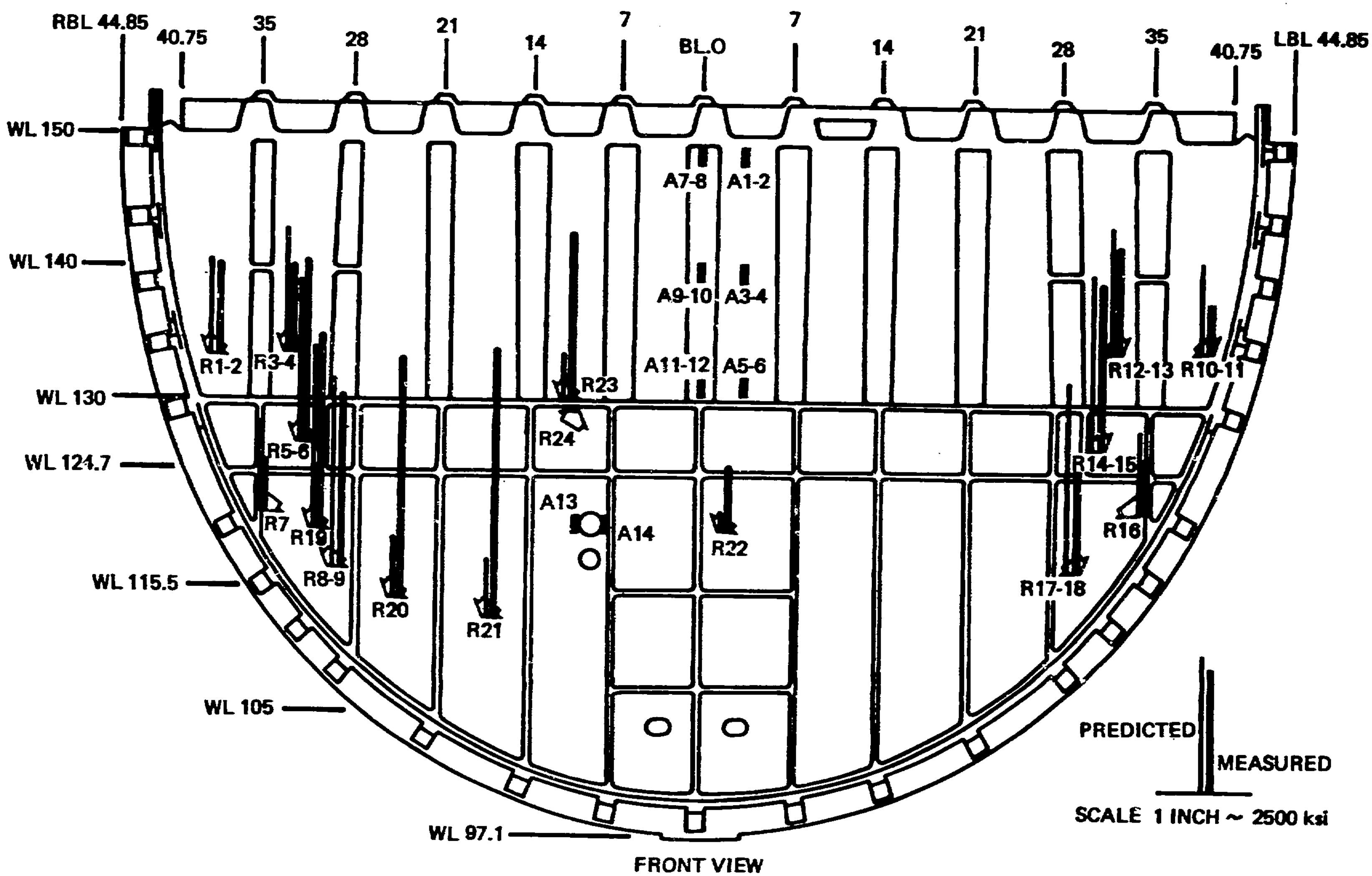


Figure 12. Results of Strain Gage Survey, Condition 2.

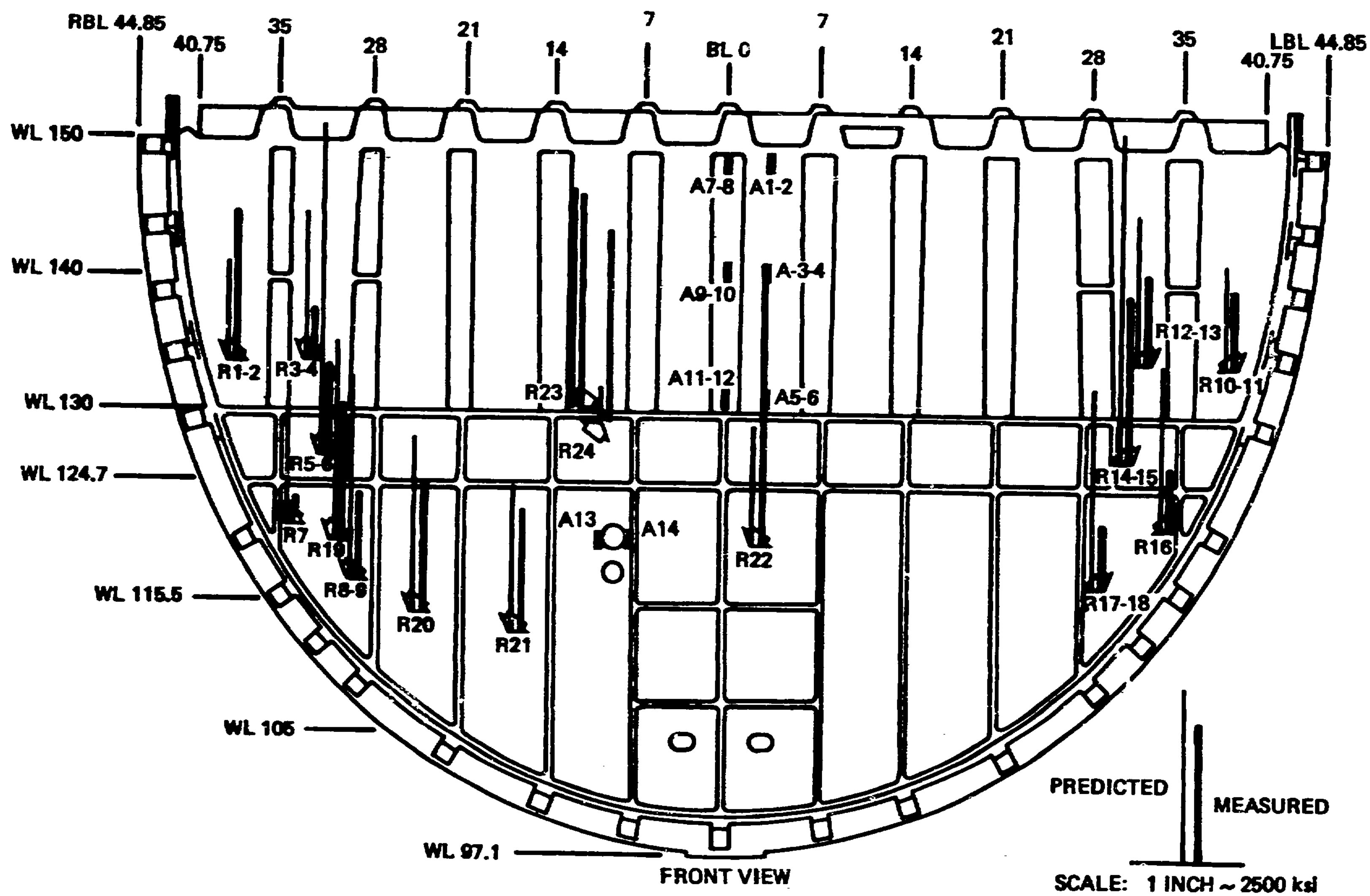


Figure 13. Results of Strain Gage Survey, Condition 3

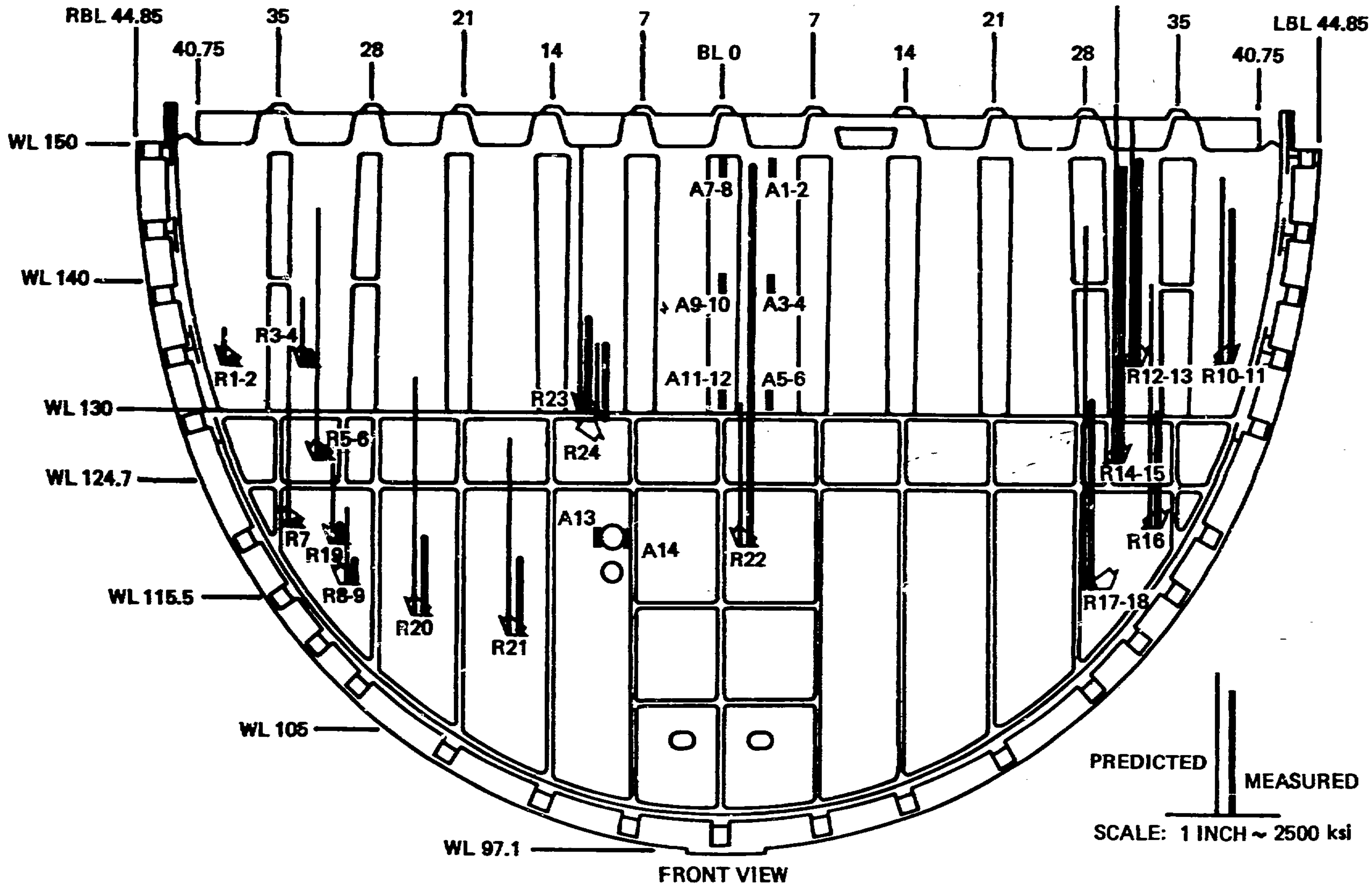


Figure 14. Results of Strain Gage Survey, Condition 4

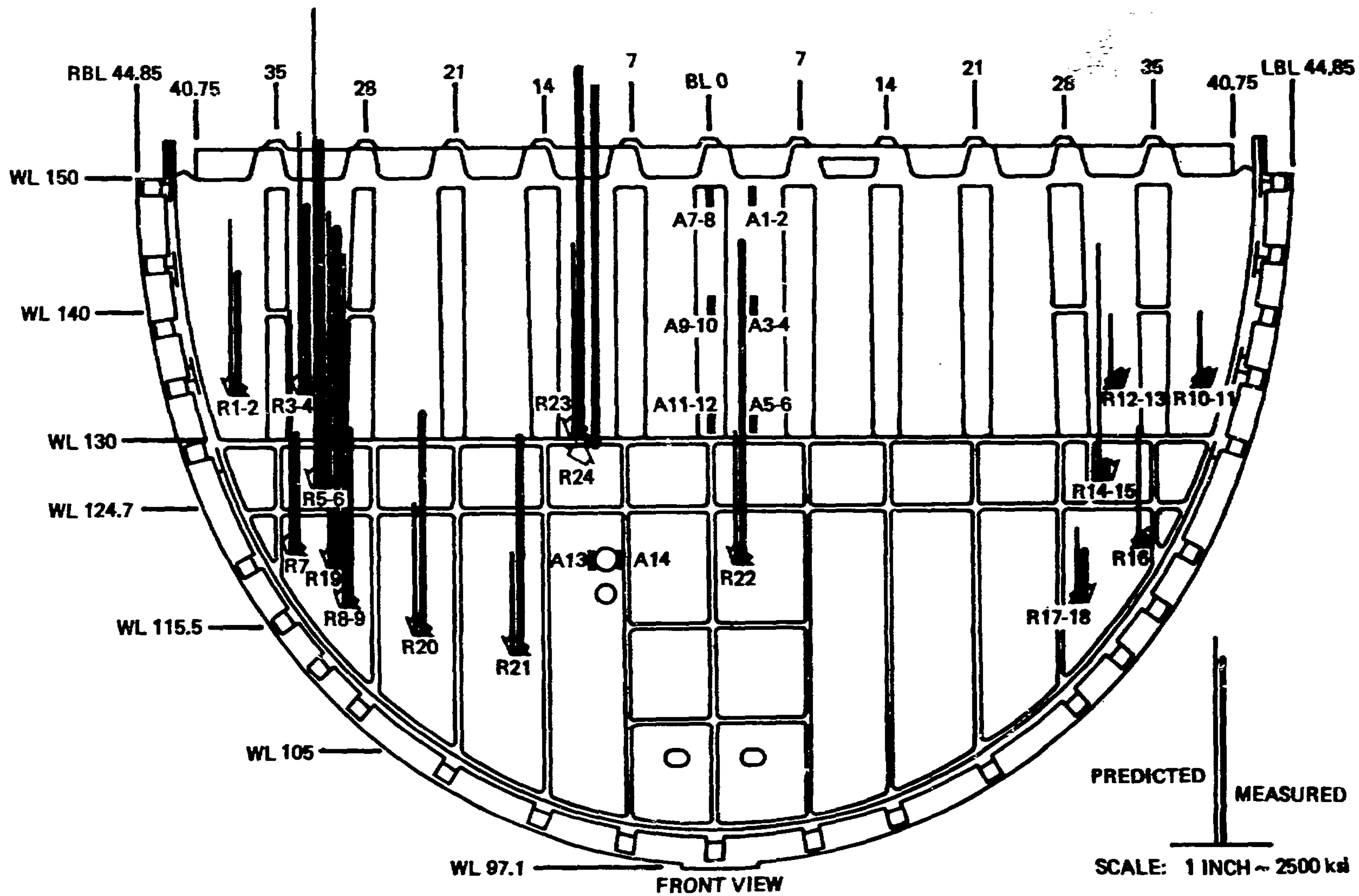


Figure 15. Results of Strain Gage Survey, Condition 5

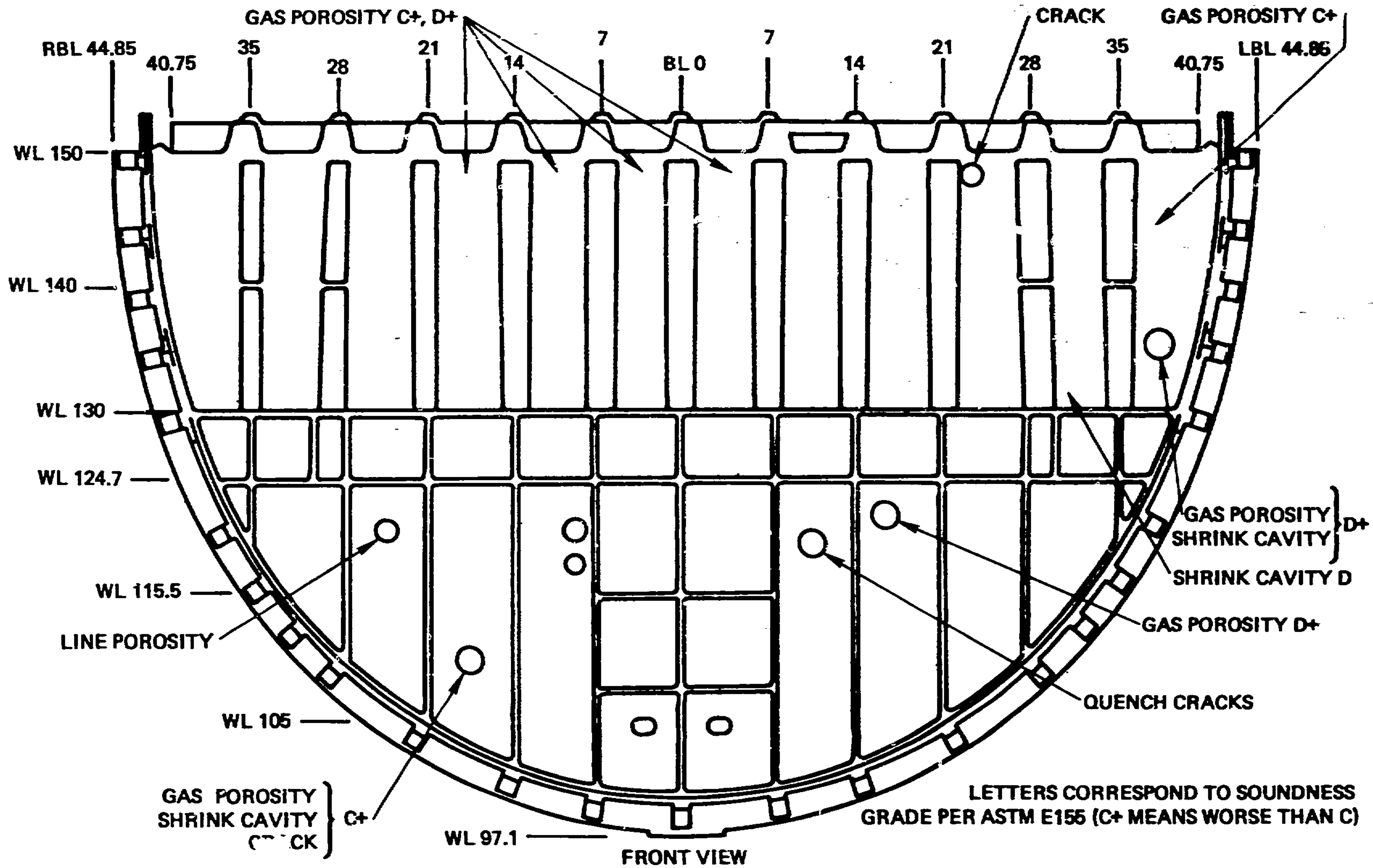


Figure 16. Initial Condition of Test Article I

Two lifetimes of simulated service were completed in March 1979. Sawcuts were then introduced into the bulkhead at most critical locations to simulate initial damage according to the damage tolerance requirements of MIL-A-83444. The location and orientation of these flaws were selected based on the finite element results and strain gage measurements. Although only surface flaws were required in some locations, it proved to be difficult to introduce these at the test site. More severe through-the-thickness sawcuts were introduced instead (Fig. 17). Load cycling was resumed, and two more lifetimes of testing were completed in July 1979 (Fig. 18). Limit loads for the Boeing side-load landing condition (Table 3) were applied to demonstrate residual strength capability.

A total of 6,294 blocks of loads (Section III.4) were applied representing slightly more than four lifetimes of service. Only small amounts of crack growth (maximum 0.008 inch) had occurred from the sawcuts, as shown in Table 7 and Figure 19. The inspections conducted during the test period did not reveal any other indications of fatigue damage to the bulkhead.

This portion of the full-scale test program did not fully demonstrate that the durability and damage requirements were met for the attachment lugs. Due to the error in the repeated loads (Section III.4), only the requirements for the bulkhead's function as a pressure bulkhead and for the redistribution of symmetric nose-gear loads were met. The demonstration of the durability and damage tolerance capability of the rest of the bulkhead was completed by conducting damage tolerance test program II, as described in the following section.

4. DAMAGE TOLERANCE TEST II

This phase of the full-scale test program began in September 1979. Test Article II had been installed in the transition structure after completion of the test program described in Section IV.3.

Strain gages were installed (Fig. 20) and limit loads corresponding to springback landing and Boeing side-load landing (Table 3) were applied. These tests were successfully completed. Strain-gage readings extrapolated to ultimate load

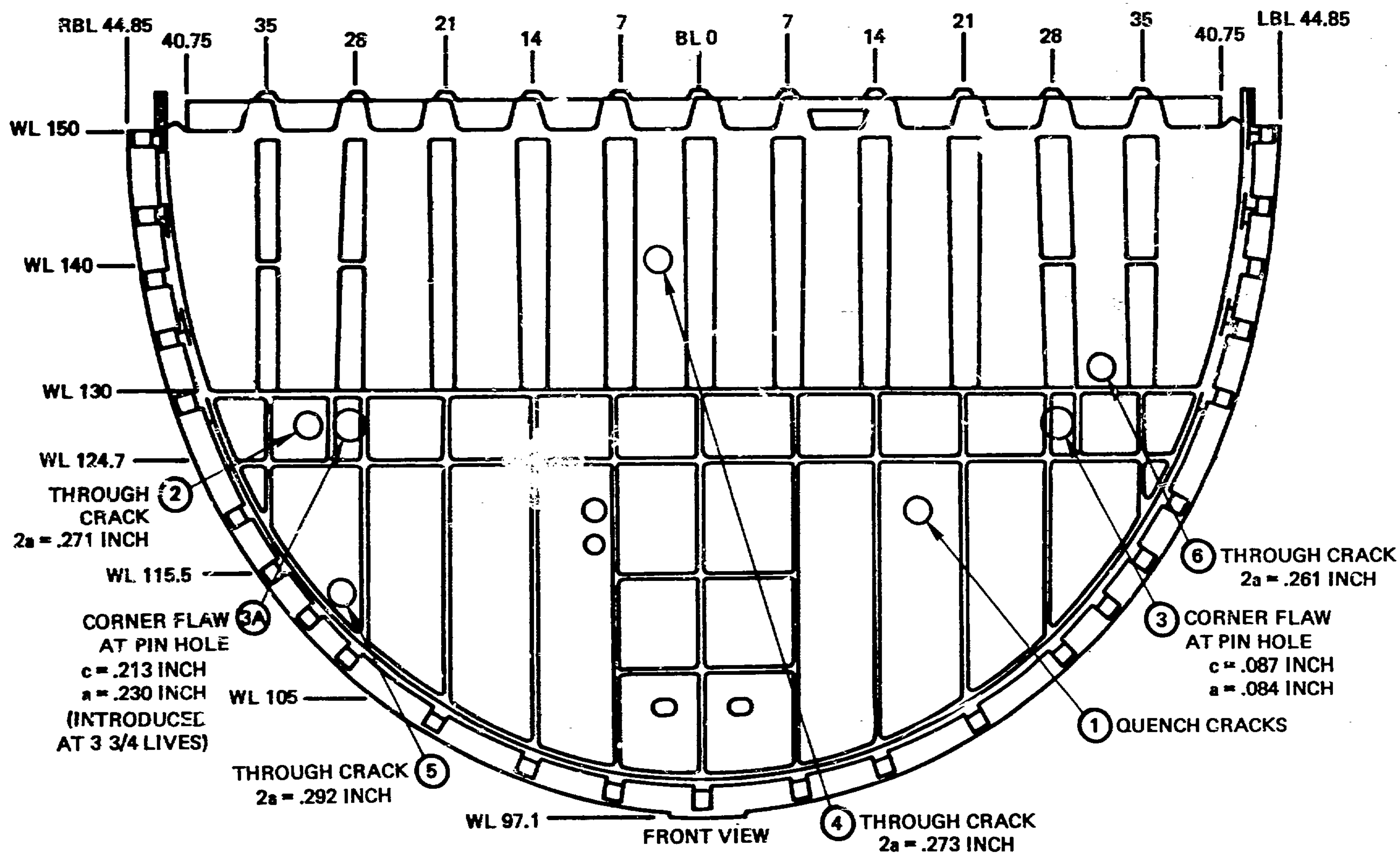


Figure 17. Initial Flaw Locations on Test Article I

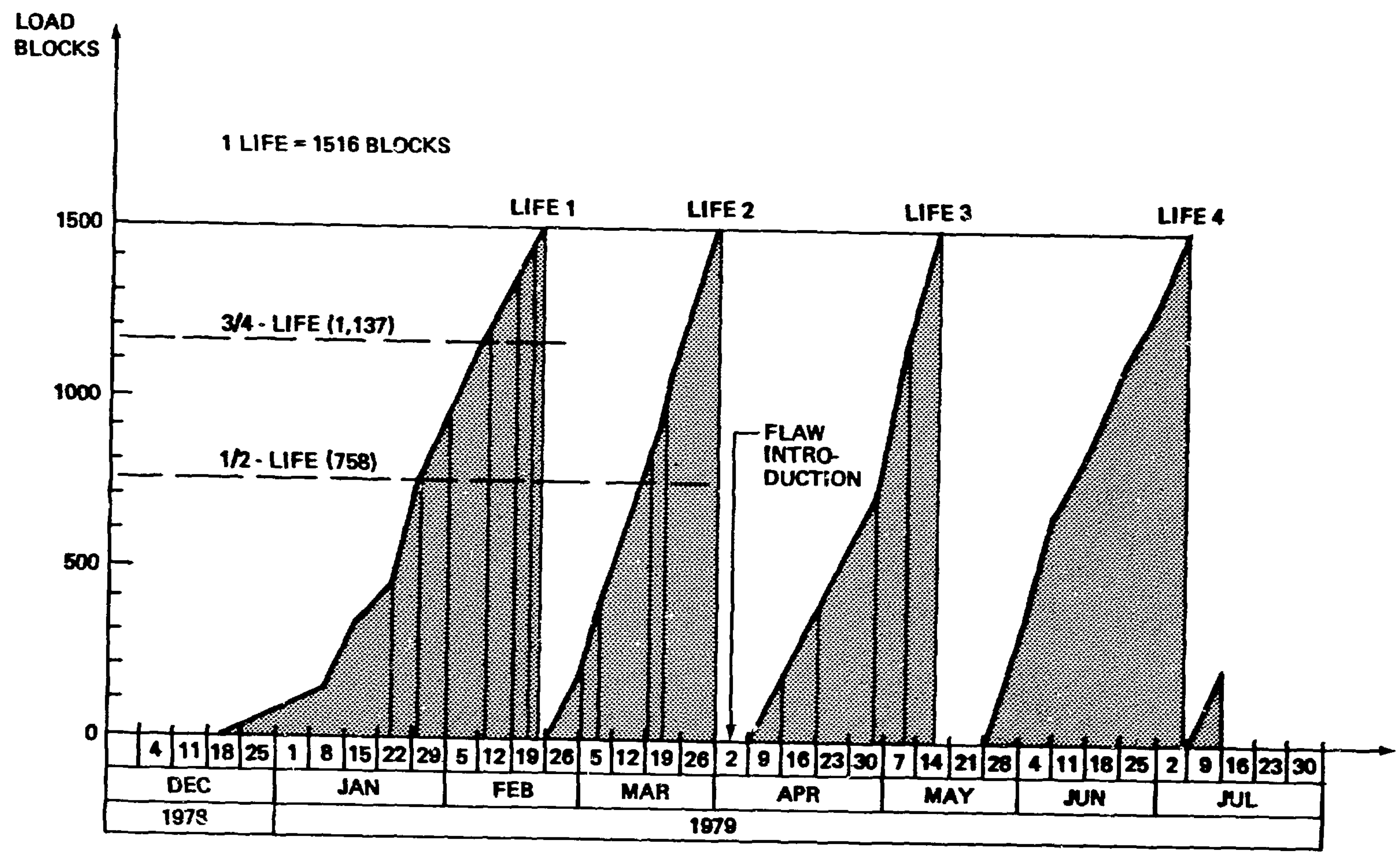


Figure 18. Test Program Progress Chart

Table 7. Crack Growth Results

Life in load blocks	Flaw number 1	2		3 a	3 c	3A a	3A c	4		5		6		Life
3032	No change	2a=0.271		0.084	0.087			2a=0.273		2a=0.292		2a=0.261		2
3807		No growth		No growth				No growth		No growth		No growth		2-1/2
4168														2-3/4
4386														2-7/8
4548														3
4548		2a=1.50						2a=1.50		2a=1.50		2a=1.50		3
4769		No growth						No growth		No growth		No growth		3-1/8
4942														3-1/4
5156												0.002		3-3/8
5384		0.0017	N.G.									0.0025	0.0011	3-1/2
5384								2a=2.50		2a=2.50				3-1/2
5535			N.G.					No growth		0.0020	N.G.	0.0025	0.0011	3-5/8
5673			0.0042					0.0028	N.G.	0.0028				3-3/4
5673						0.230	0.213							3-3/4
5901			0.0042			No growth		0.0034		0.0034			0.0011	3-7/8
6064			0.0076					0.0056		0.0056		0.0025	0.0034	4
6294		0.0017	0.0076					0.008	0.002	0.0070	0.0039	0.0028	0.0034	4+

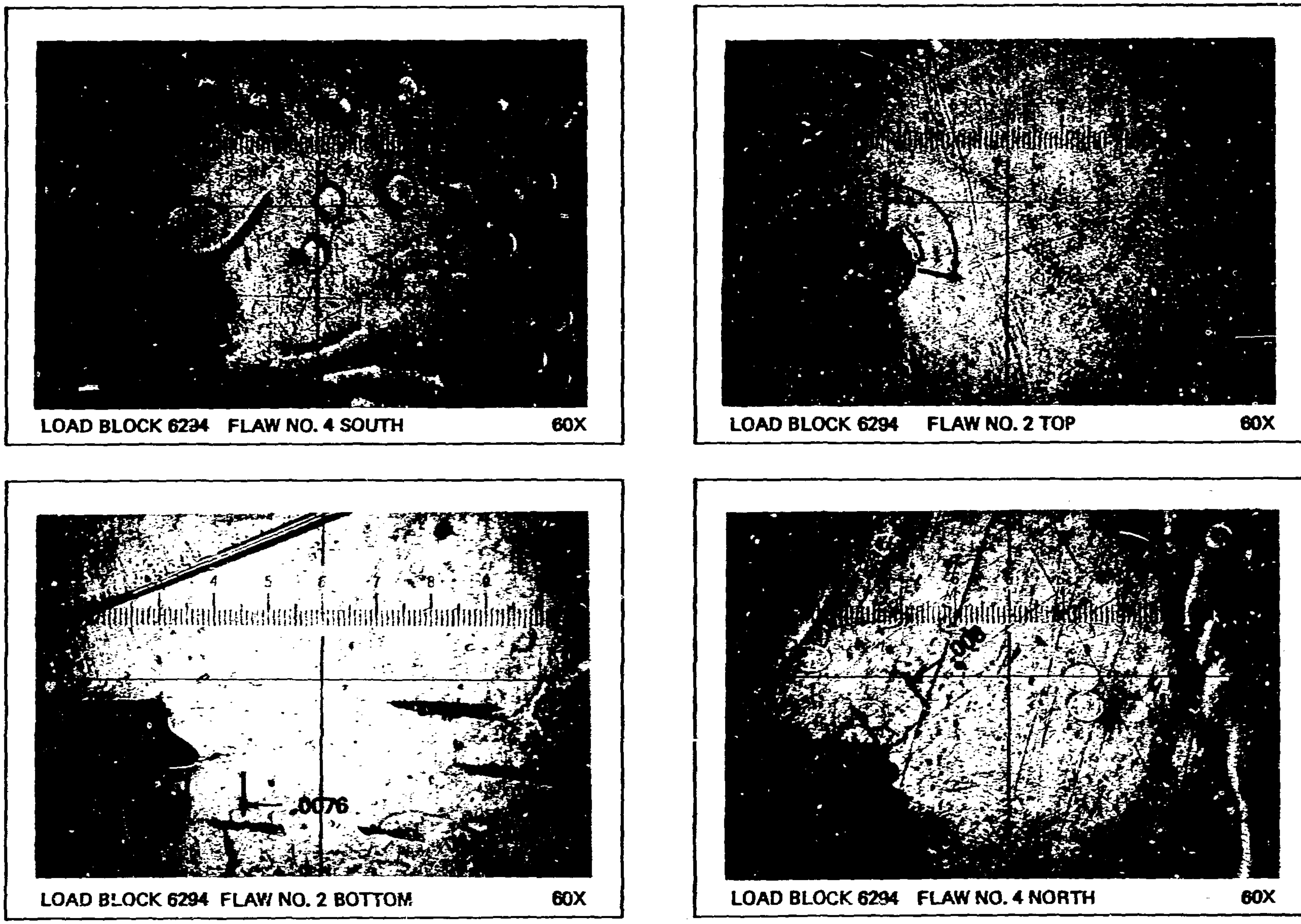


Figure 19. Crack Growth from Initial Flaws

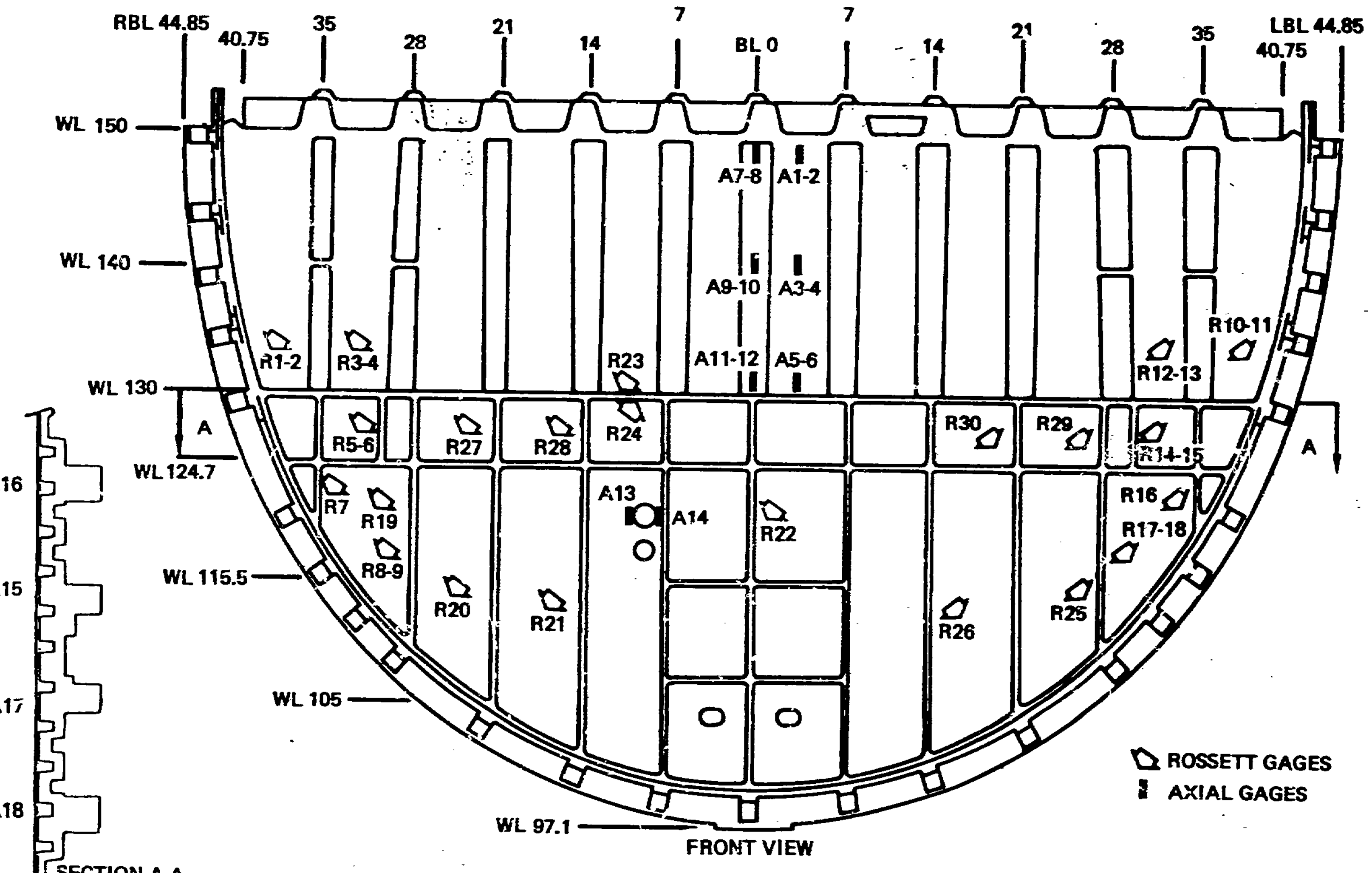


Figure 20. Strain Gage Locations on Test Article II

conditions indicated that the bulkhead and transition structure would sustain ultimate loads without failure.

Initial damage was introduced (Fig. 21) according to the damage tolerance requirements of MIL-A-83444. Cyclic loads (Appendix B) corresponding to two lives of design service usage were then applied. Inspections were conducted during the test program as described in Section IV.3.

The cyclic loading was completed in November 1979 (Fig. 22). No fatigue damage was discovered during or after completion of the program. Residual strength tests were carried out following the completion of the cyclic test to determine the load-carrying capacity of the preflawed bulkhead that had been subjected to two lifetimes of simulated service usage. The two ultimate conditions (springback landing and Boeing side-load landing) were first applied, each to 100 percent of ultimate. No visible damage or permanent deformations were observed demonstrating that the static strength requirements for the bulkhead were met and that the residual strength capacity of the bulkhead was at least equivalent to the ultimate load. To further study the residual strength capability, another sawcut (Fig. 21) was introduced before the application of more loads. Loads corresponding to the Boeing side-load landing condition again were applied. The bulkhead and the transition structure withstood these loads sucessfully to 120 percent of ultimate. Since this presented the limit of the load application and reaction system, the test was suspended at this level. No failures occurred during the test and no permanent deformation was observed after the test. Strain-gage data plots from the residual strength tests are contained in Appendix C. The maximum stresses were measured at strain gage R15 (Fig. 20) during the Boeing side-load landing condition. The maximum shear stress measured at ultimate was 14 ksi, which agrees well with the predicted shear stress of 13.6 ksi (ref. 1).

The successful completion of this portion of the full-scale test program demonstrated that the cast bulkhead met all durability and damage tolerance requirements of MIL-A-008866B (USAF) and MIL-A-83444 (USAF).

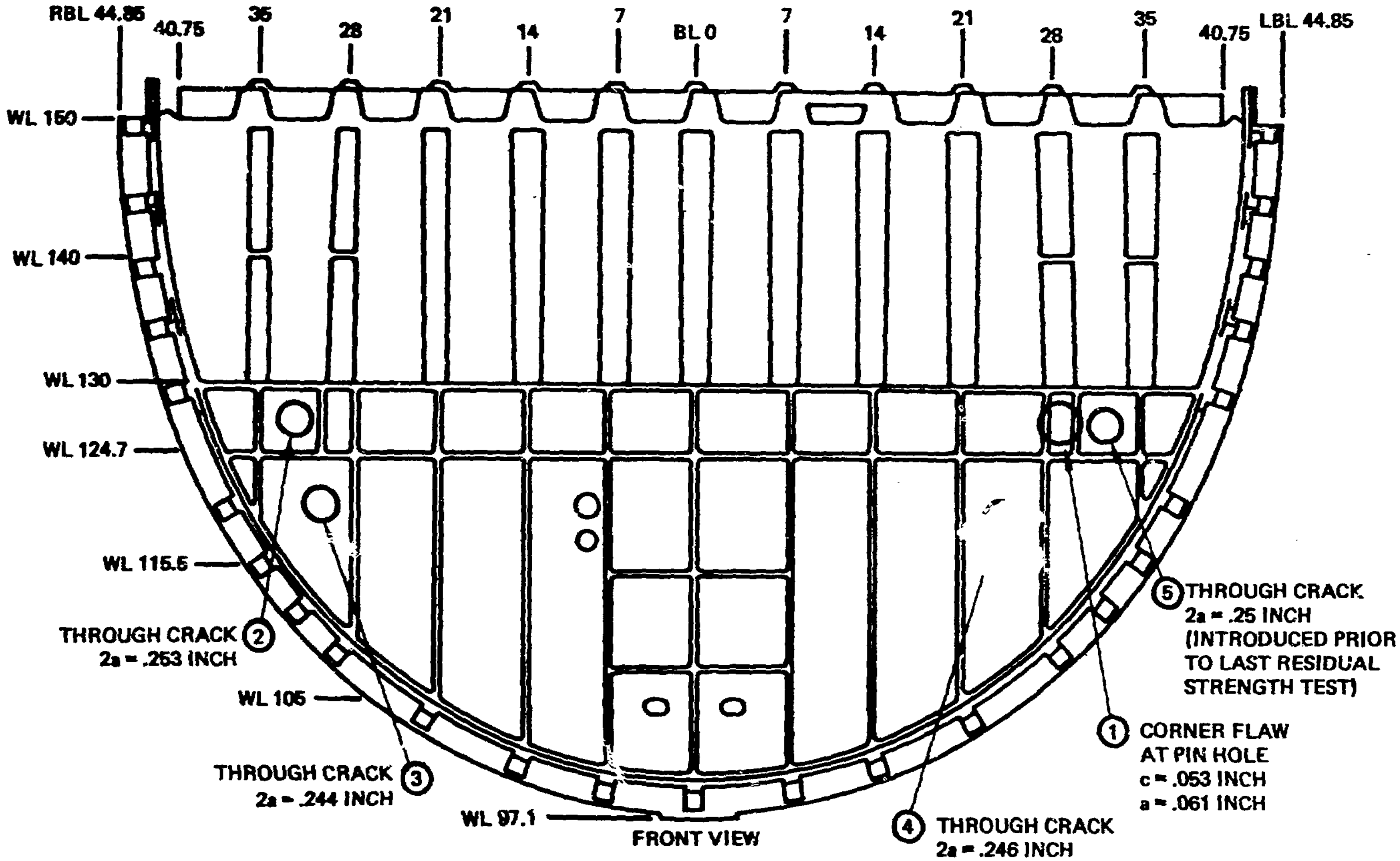


Figure 21. Initial Flaw Locations on Test Article II

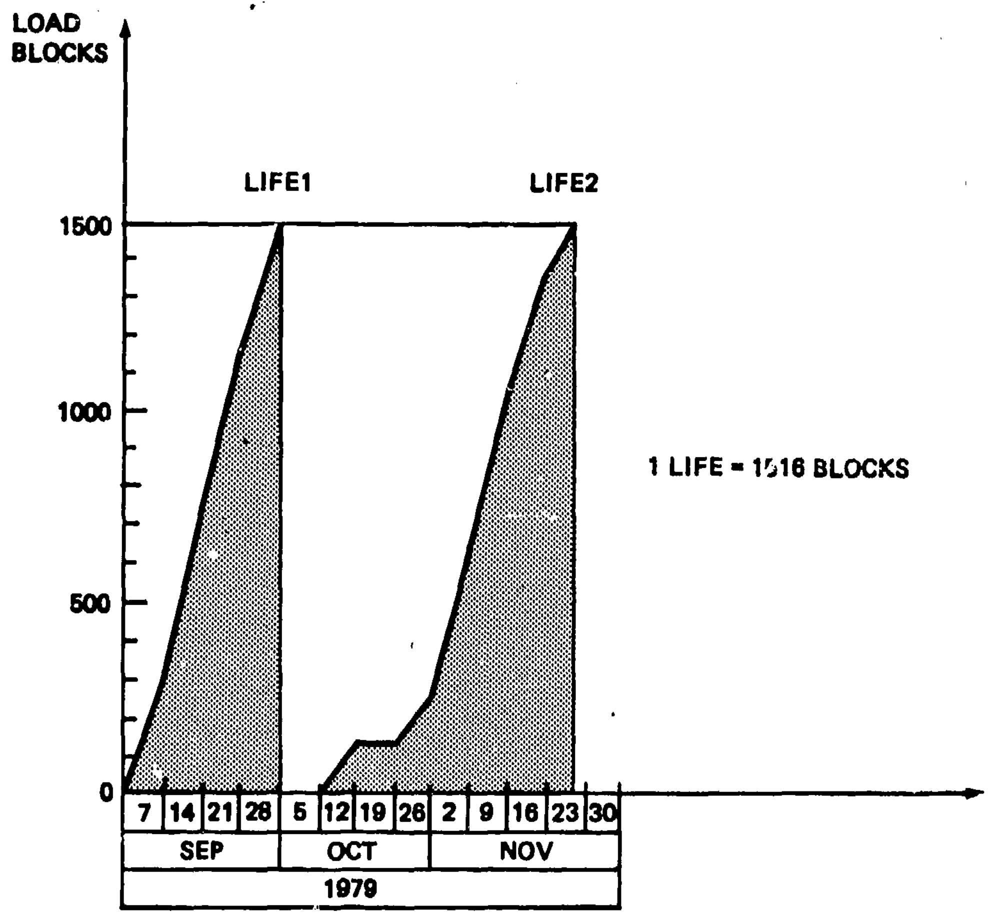


Figure 22. Test Program Progress Chart

SECTION V
CONCLUSIONS AND RECOMMENDATIONS

During the course of the CAST program, a CAST primary aircraft structure component was produced without a weight penalty and its structural integrity was demonstrated by analysis and full-scale test.

The cost savings offered by this casting technology (35 percent for 300 bulkheads compared to the cost of the built-up bulkhead) and the successful completion of the CAST program provide a basis for continued development of this technology. The next step should be to demonstrate the integrity of a cast primary structure in service. Simultaneously, additional development work should be performed, in particular, the nondestructive evaluation of static mechanical and fatigue and fracture properties of castings should be further developed. Also, more data should be generated concerning the quantitative analysis of effects of defects. A follow-on program to the CAST program is planned to identify the physical and process variables that significantly influence elongation. The objective of this program is to improve the minimum elongation of castings. Increased minimum elongation will go a long way toward increasing confidence in the application of casting technology to primary aircraft structure.

REFERENCES

1. D. Goehler, Cast Aluminum Structures Technology, Phase III (CAST), AFFDL-TR-78-7.

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APPENDIX A

REPEATED LOADS FOR DURABILITY AND DAMAGE TOLERANCE (I) TESTS

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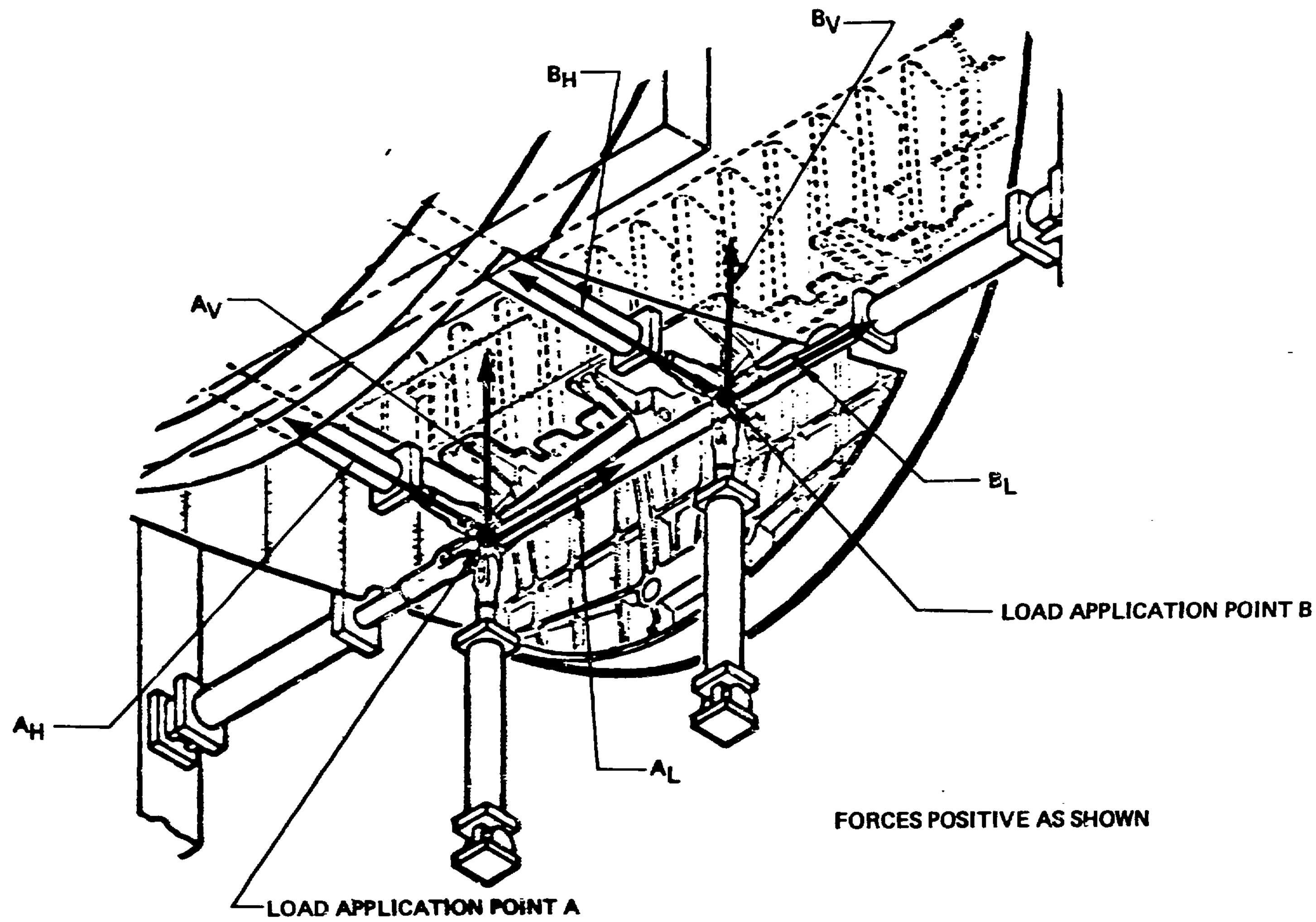

Figure A-1. Test Load Components at Load Application Points

Table A-1. Test Load Spectrum Block

		Load Point 1*						Load Point 2*						
Flight	Load Level	A_V	A_H	A_L	B_V	B_H	B_L	A_V	A_H	A_L	B_V	B_H	B_L	Cycles
Type 1	T3	0.76	- 8.53	0	0.76	- 8.53	0	1.26	-14.22	0	1.26	-14.22	0	22
	T4	0.66	- 7.39	0	0.66	- 7.39	0	1.36	-15.36	0	1.36	-15.36	0	2
	P1	0 PSI TO 6.55 PSI TO 0 PSI												
	LCH**													1
	B1	1.01	-11.38	0	1.01	-11.38	0	1.72	-19.43	0	1.72	-19.43	0	5
	B2	1.01	-11.38	0	1.01	-11.38	0	2.44	-27.49	0	2.44	-27.49	0	2
	SL1	0	0	0	0	0	0	12.07	5.41	- 7.20	-12.07	- 5.41	0	1
	SR1	0	0	0	0	0	0	-12.07	- 5.41	0	12.07	5.41	7.20	1
	TL1	1.01	-11.38	0	1.01	-11.38	0	21.12	- 2.36	-12.00	-19.10	-20.39	0	1
	TR1	1.01	-11.38	0	1.01	-11.38	0	-19.10	-20.39	0	21.12	- 2.36	12.00	1
Type 2	T3	.76	- 8.53	0	.76	- 8.53	0	1.26	-14.22	0	1.26	-14.22	0	22
	T4	.66	- 7.39	0	.66	- 7.39	0	1.36	-15.36	0	1.36	-15.36	0	2
	LCH**													1
	B1	1.01	-11.38	0	1.01	-11.38	0	1.72	-19.43	0	1.72	-19.43	0	5
	B2	1.01	-11.38	0	1.01	-11,38	0	2.44	-27.49	0	2.44	-27.49	0	2
	SL1	0	0	0	0	0	0	12.07	5.41	0	-12.07	- 5.41	7.20	1
	SR1	0	0	0	0	0	0	-12.07	- 5.41	- 7.20	12.07	5.41	0	1
	TL1	1.01	-11.38	0	1.01	-11.38	0	21.12	- 2.36	0	-19.10	-20.39	12.00	1
	TR1	1.01	-11.38	0	1.01	-11.38	0	-19.10	-20.39	-12.00	21.12	- 2.36	0	1
Type 2	Repeat													
Type 2	Repeat													
Type 2	Repeat													
Type 3	T3	-1.54	- 7.86	0	-1.54	- 7.86	0	- 2.57	-13.10	0	- 2.57	-13.10	0	44
	T4	-1.34	- 6.81	0	-1.34	- 6.81	0	- 2.78	-14.15	0	- 2.78	-14.15	0	4
	LS**													1
	B1	0.84	- 9.48	0	0.84	- 9.48	0	1.66	-18.72	0	1.66	-18.72	0	5
	B2	0.84	- 9.48	0	0.94	- 9.4	0	2.06	-23.23	0	2.06	-23.23	0	2
	SL1	0	0	0	0	0	0	10.06	4.51	0	-10.06	- 4.51	6.00	1
	SL2	0	0	0	0	0	0	-10.06	- 4.51	- 6.00	10.06	4.51	0	1
	TL1	0.84	- 9.48	0	0.84	- 9.48	0	17.60	- 1.97	0	-15.92	-16.99	10.00	1
	TR1	0.84	- 9.48	0	0.84	- 9.48	0	-15.92	-16.99	-10.00	17.60	- 1.97	0	1
Type 3	Repeat													
Type 3	Repeat													

Table A-1. Test Load Spectrum Block (Concluded)

Flight	Load level	Load point 1* A_V	A_H	A_L	B_V	B_H	B_L	Load point 2* A_V	A_H	A_L	B_V	B_H	B_L	Cycles
Type 4	T3	0.63	- 7.11	0	0.63	- 7.11	0	1.05	-11.85	0	1.05	-11.85	0	22
	T4	0.55	- 6.16	0	0.55	- 6.16	0	1.13	-12.80	0	1.13	-12.80	0	2
	P1	0 PSI TO 6.55 PSI TO 0 PSI												1
	LCL**													2
	B1	0.84	- 9.48	0	0.84	- 9.48	0	1.66	-18.72	0	1.66	-18.72	0	5
	B2	0.84	- 9.48	0	0.84	- 9.48	0	2.06	-23.23	0	2.06	-23.23	0	2
	SL1	0	0	0	0	0	0	10.06	4.51	0	-10.06	- 4.51	6.00	1
	SR1	0	0	0	0	0	0	-10.06	- 4.51	- 6.00	10.06	4.51	0	1
	TL1	0.84	- 9.48	0	0.84	- 9.48	0	17.60	- 1.97	0	-15.92	-16.99	10.00	1
	TR1	0.84	- 9.48	0	0.84	- 9.48	0	-15.92	-16.99	-10.00	17.60	- 1.97	0	1
Type 4	Repeat													
Type 4	Repeat													
Type 4	Repeat													
Type 4	Repeat													
Type 5	T3	-1.54	- 7.86	0	-1.54	- 7.86	0	- 2.57	-13.10	0	- 2.57	-13.10	0	44
	T4	-1.34	- 6.81	0	-1.34	- 6.81	0	- 2.78	-14.15	0	- 2.78	-14.15	0	4
	P1	0 PSI TO 6.55 PSI TO 0 PSI												1
	LS**													2
	B1	-2.06	-10.48	0	-2.06	-10.48	0	- 4.06	-20.70	0	- 4.06	-20.70	0	5
	B2	-2.06	-10.48	0	-2.06	-10.48	0	- 5.04	-25.68	0	- 5.04	-25.68	0	2
	SL1	0	0	0	0	0	0	10.06	4.51	0	-10.06	- 4.51	6.00	1
	SR1	0	0	0	0	0	0	-10.06	- 4.51	- 6.00	10.06	4.51	0	1
	TL1	0.84	- 9.48	0	0.84	- 9.48	0	17.60	- 1.97	0	-15.92	-16.99	10.00	1
	TR1	0.84	- 9.48	0	0.84	- 9.48	0	-15.92	-16.99	-10.00	17.60	- 1.97	0	1
Type 5	Repeat													
Type 5	Repeat													

* Loads are in kips

** Landing conditions: LCH - See Table A2
LCL - See Table A3
LS - See Table A4

Table A-2. Load Points for CTOL Landing Conditions (GW=162 kips)

Load Level	Load Point 1*						Load Point 2*						Load Point 3*						Occur-rences
	A_V	A_H	A_L	B_V	B_H	B_L	A_V	A_H	A_L	B_V	B_H	B_L	A_V	A_H	A_L	B_V	B_H	B_L	
LCH1.1	0	0	0	0	0	0	-11.16	-15.58	0	-11.16	-15.58	0	7.09	9.28	0	7.09	- 9.28	0	312
LCH1.2	0	0	0	0	0	0	13.08	- 5.97	0	-11.06	-16.78	7.20	0	0	0	0	0	0	80
LCH1.3	0	0	0	0	0	0	-11.06	-16.78	- 7.20	13.08	- 5.97	0	0	0	0	0	0	0	80
LCH2.1	0	0	0	0	0	0	-12.55	-17.52	0	-12.55	-17.52	0	8.01	-10.42	0	8.01	-10.42	0	174
LCH2.2	0	0	0	0	0	0	14.71	- 6.71	0	-12.44	-18.88	0	0	0	0	0	0	0	42
LCH2.3	0	0	0	0	0	0	-12.44	-18.88	- 8.10	14.71	- 6.71	0	0	0	0	0	0	0	42
LCH3.1	0	0	0	0	0	0	-16.73	-23.36	0	-16.73	-23.36	0	10.63	-13.91	0	10.63	-13.91	0	104
LCH3.2	0	0	0	0	0	0	19.61	- 8.95	0	-16.59	-25.17	10.80	0	0	0	0	0	0	26
LCH3.3	0	0	0	0	0	0	-16.59	-25.17	-10.80	19.61	- 8.95	0	0	0	0	0	0	0	26
LCH4.1	0	0	0	0	0	0	-20.92	-29.21	0	-20.92	-29.21	0	13.33	-17.38	0	13.33	-17.38	0	52
LCH4.2	0	0	0	0	0	0	24.52	-11.19	0	-20.74	-31.47	13.50	0	0	0	0	0	0	12
LCH4.3	0	0	0	0	0	0	-20.74	-31.47	-13.50	24.52	-11.19	0	0	0	0	0	0	0	12
LCH5.1	0	0	0	0	0	0	-25.10	-35.05	0	-25.10	-35.05	0	15.95	-20.87	0	15.95	-20.87	0	18
LCH5.2	0	0	0	0	0	0	29.42	-13.43	0	-24.88	-37.76	16.20	0	0	0	0	0	0	4
LCH5.3	0	0	0	0	0	0	-24.98	-37.76	-16.20	29.42	-13.43	0	0	0	0	0	0	0	4
LCH6.1	0	0	0	0	0	0	-29.28	-40.89	0	-29.28	-40.89	0	18.65	-24.34	0	18.65	-24.34	0	4
LCH6.2	0	0	0	0	0	0	34.32	-15.67	0	-29.03	-44.05	18.90	0	0	0	0	0	0	2
LCH6.3	0	0	0	0	0	0	-29.03	-44.05	-18.90	34.32	-15.67	0	0	0	0	0	0	0	2
LCH7.1	0	0	0	0	0	0	-33.47	-46.72	0	-33.47	-46.72	0	21.27	-27.82	0	21.27	-27.82	0	2
LCH8.1	0	0	0	0	0	0	-37.65	-52.57	0	-37.65	-52.57	0	23.96	-31.29	0	23.96	-31.29	0	2

* Loads are in kips

Table A-3. Load Points for CTOL Landing Conditions (GW=136 kips)

Load level	Load point 1*						Load point 2*						Load point 3*						Occurrences
	A_V	A_H	A_L	B_V	B_H	B_L	A_V	A_H	A_L	B_V	B_H	B_L	A_V	A_H	A_L	B_V	B_H	B_L	
LCL1.1	0	0	0	0	0	0	- 9.30	-12.98	0	- 9.30	-12.98	0	5.91	- 7.73	0	5.91	- 7.73	0	624
LCL1.2	0	0	0	0	0	0	10.90	- 4.97	0	- 9.22	-13.99	6.00	0	0	0	0	0	0	158
LCL1.3	0	0	0	0	0	0	- 9.22	-13.99	6.00	10.90	- 4.97	0	0	0	0	0	0	0	158
LCL2.1	0	0	0	0	0	0	-12.55	-17.52	0	-12.55	-17.52	0	8.01	-10.42	0	8.01	-10.42	0	343
LCL2.2	0	0	0	0	0	0	14.71	- 6.71	0	-12.44	-18.88	8.10	0	0	0	0	0	0	86
LCL2.3	0	0	0	0	0	0	-12.44	-18.88	- 8.10	14.71	- 6.71	0	0	0	0	0	0	0	86
LCL3.1	0	0	0	0	0	0	-16.73	-23.36	0	-16.73	-23.36	0	10.63	-13.91	0	10.63	-13.91	0	206
LCL3.2	0	0	0	0	0	0	19.61	- 8.95	0	-16.59	-25.17	10.80	0	0	0	0	0	0	52
LCL3.3	0	0	0	0	0	0	-16.59	-25.17	-10.80	19.61	- 8.95	0	0	0	0	0	0	0	52
LCL4.1	0	0	0	0	0	0	-20.92	-29.21	0	-20.92	-29.21	0	13.33	-17.38	0	13.33	-17.38	0	104
LCL4.2	0	0	0	0	0	0	24.52	-11.19	0	-20.74	-31.47	13.50	0	0	0	0	0	0	26
LCL4.3	0	0	0	0	0	0	-20.74	-31.47	-13.50	24.52	-11.19	0	0	0	0	0	0	0	26
LCL5.1	0	0	0	0	0	0	-25.10	-35.05	0	-25.10	-35.05	0	15.95	-20.87	0	15.95	-20.87	0	36
LCL5.2	0	0	0	0	0	0	29.42	-13.43	0	-24.88	-37.76	16.20	0	0	0	0	0	0	8
LCL5.3	0	0	0	0	0	0	-24.88	-37.76	-16.20	29.42	-13.43	0	0	0	0	0	0	0	8
LCL6.1	0	0	0	0	0	0	-29.28	-40.89	0	-29.28	-40.89	0	18.65	-24.34	0	18.65	-24.34	0	12
LCL6.2	0	0	0	0	0	0	34.32	-15.67	0	-29.03	-44.05	18.90	0	0	0	0	0	0	3
LCL6.3	0	0	0	0	0	0	-29.03	-44.05	-18.90	34.32	-15.67	0	0	0	0	0	0	0	2
LCL7.1	0	0	0	0	0	0	-33.47	-47.62	0	-33.47	-47.62	0	21.27	-27.82	0	21.27	-27.82	0	3
LCL8.1	0	0	0	0	0	0	-37.65	-52.57	0	-37.65	-52.57	0	23.96	-31.29	0	23.96	-31.29	0	2

*loads are in kips

Table A-4. Load Points for STOL Landing Conditions

Load level	Load point 1*						Load point 2*						Load point 3*						Occurrences
	A_V	A_H	A_L	B_V	B_H	B_L	A_V	A_H	A_L	B_V	B_H	B_L	A_V	A_H	A_L	B_V	B_H	B_L	
LS1.1	0	0	0	0	0	0	- 9.30	-12.98	0	- 9.30	-12.98	0	5.91	- 7.73	0	5.91	- 7.73	0	16
LS1.2	0	0	0	0	0	0	10.90	- 4.97	0	- 9.22	-13.99	6.00	0	0	0	0	0	0	4
LS1.3	0	0	0	0	0	0	- 9.22	-13.99	- 6.00	10.90	- 4.97	0	0	0	0	0	0	0	4
LS2.1	0	0	0	0	0	0	-12.55	-17.52	0	-12.55	-17.52	0	8.01	-10.42	0	8.01	-10.42	0	44
LS2.2	0	0	0	0	0	0	14.71	- 6.71	0	-12.44	-18.88	8.10	0	0	0	0	0	0	12
LS2.3	0	0	0	0	0	0	-12.44	-18.88	- 8.10	14.71	- 6.71	0	0	0	0	0	0	0	12
LS3.1	0	0	0	0	0	0	-16.73	-23.36	0	-16.73	-23.36	0	10.63	-13.91	0	10.63	-13.91	0	98
LS3.2	0	0	0	0	0	0	19.61	- 8.95	0	-16.59	-25.17	10.80	0	0	0	0	0	0	24
LS3.3	0	0	0	0	0	0	-16.59	-25.17	-10.80	19.61	- 8.95	0	0	0	0	0	0	0	24
LS4.1	0	0	0	0	0	0	-20.92	-29.21	0	-20.92	-29.21	0	13.33	-17.38	0	13.33	-17.38	0	116
LS4.2	0	0	0	0	0	0	24.52	-11.19	0	-20.74	-31.47	13.50	0	0	0	0	0	0	28
LS4.3	0	0	0	0	0	0	-20.74	-31.47	-13.50	24.52	-11.19	0	0	0	0	0	0	0	28
LS5.1	0	0	0	0	0	0	-25.10	-35.05	0	-25.10	-35.05	0	15.95	-20.87	0	15.95	-20.87	0	112
LS5.2	0	0	0	0	0	0	29.42	-13.43	0	-24.88	-37.76	16.20	0	0	0	0	0	0	28
LS5.3	0	0	0	0	0	0	-24.88	-37.76	-16.20	29.42	-13.43	0	0	0	0	0	0	0	28
LS6.1	0	0	0	0	0	0	-29.28	-40.89	0	-29.28	-40.89	0	18.65	-24.34	0	18.65	-24.34	0	106
LS6.2	0	0	0	0	0	0	34.32	-15.67	0	-29.03	-44.05	18.90	0	0	0	0	0	0	26
LS6.3	0	0	0	0	0	0	-29.03	-44.05	-18.90	34.32	-15.67	0	0	0	0	0	0	0	26
LS7.1	0	0	0	0	0	0	-33.47	-47.62	0	-33.47	-47.62	0	21.27	-27.82	0	21.27	-27.82	0	72
LS7.2	0	0	0	0	0	0	39.23	-17.91	0	-33.18	-50.35	21.60	0	0	0	0	0	0	18
LS7.3	0	0	0	0	0	0	-33.18	-50.35	-21.60	39.23	-17.91	0	0	0	0	0	0	0	18
LS8.1	0	0	0	0	0	0	-37.65	-52.57	0	-37.65	-52.57	0	23.96	-31.29	0	23.96	-31.29	0	46
LS8.2	0	0	0	0	0	0	44.13	-20.14	0	-37.32	-56.64	24.30	0	0	0	0	0	0	10
LS8.3	0	0	0	0	0	0	-37.32	-56.64	-24.30	44.13	-20.14	0	0	0	0	0	0	0	10
LS9.1	0	0	0	0	0	0	-41.37	-57.76	0	-41.37	-57.76	0	26.33	-34.39	0	26.33	-34.39	0	28
LS9.2	0	0	0	0	0	0	48.49	-22.13	0	-41.01	-62.24	26.70	0	0	0	0	0	0	8
LS9.3	0	0	0	0	0	0	-41.01	-62.24	-26.70	48.49	-22.13	0	0	0	0	0	0	0	8
LS10.1	0	0	0	0	0	0	-46.02	-64.25	0	-46.02	-64.25	0	26.75	-39.13	0	26.75	-39.13	0	14
LS10.2	0	0	0	0	0	0	52.38	-1.17	0	-48.18	-46.23	30.00	0	0	0	0	0	0	4
LS10.3	0	0	0	0	0	0	-48.18	-46.23	-30.00	52.38	- 1.17	0	0	0	0	0	0	0	4
LS11.1	0	0	0	0	0	0	-50.20	-70.09	0	-50.20	-70.09	0	31.90	-41.74	0	31.90	-41.74	0	10
LS11.2	0	0	0	0	0	0	52.38	- 1.17	0	-48.18	- 46.23	30.00	0	0	0	0	0	0	2
LS11.3	0	0	0	0	0	0	-48.18	-46.23	-30.00	52.38	- 1.17	0	0	0	0	0	0	0	2
LS12.1	0	0	0	0	0	0	-54.38	-75.93	0	-54.38	-75.93	0	34.60	-45.21	0	34.60	-45.21	0	2
LS12.2	0	0	0	0	0	0	52.38	- 1.17	0	-48.18	-46.23	30.00	0	0	0	0	0	0	2
LS12.3	0	0	0	0	0	0	-48.18	-46.23	-30.00	52.38	- 1.17	0	0	0	0	0	0	0	2
LS13.1	0	0	0	0	0	0	-59.03	-82.42	0	-59.03	-82.42	0	37.55	-49.07	0	37.55	-49.07	0	2
LS14.1	0	0	0	0	0	0	-62.75	-87.62	0	-62.75	-87.62	0	39.92	-52.17	0	39.92	-52.17	0	2

*Loads are in kips

APPENDIX B

REPEATED LOADS FOR DAMAGE TOLERANCE TEST II

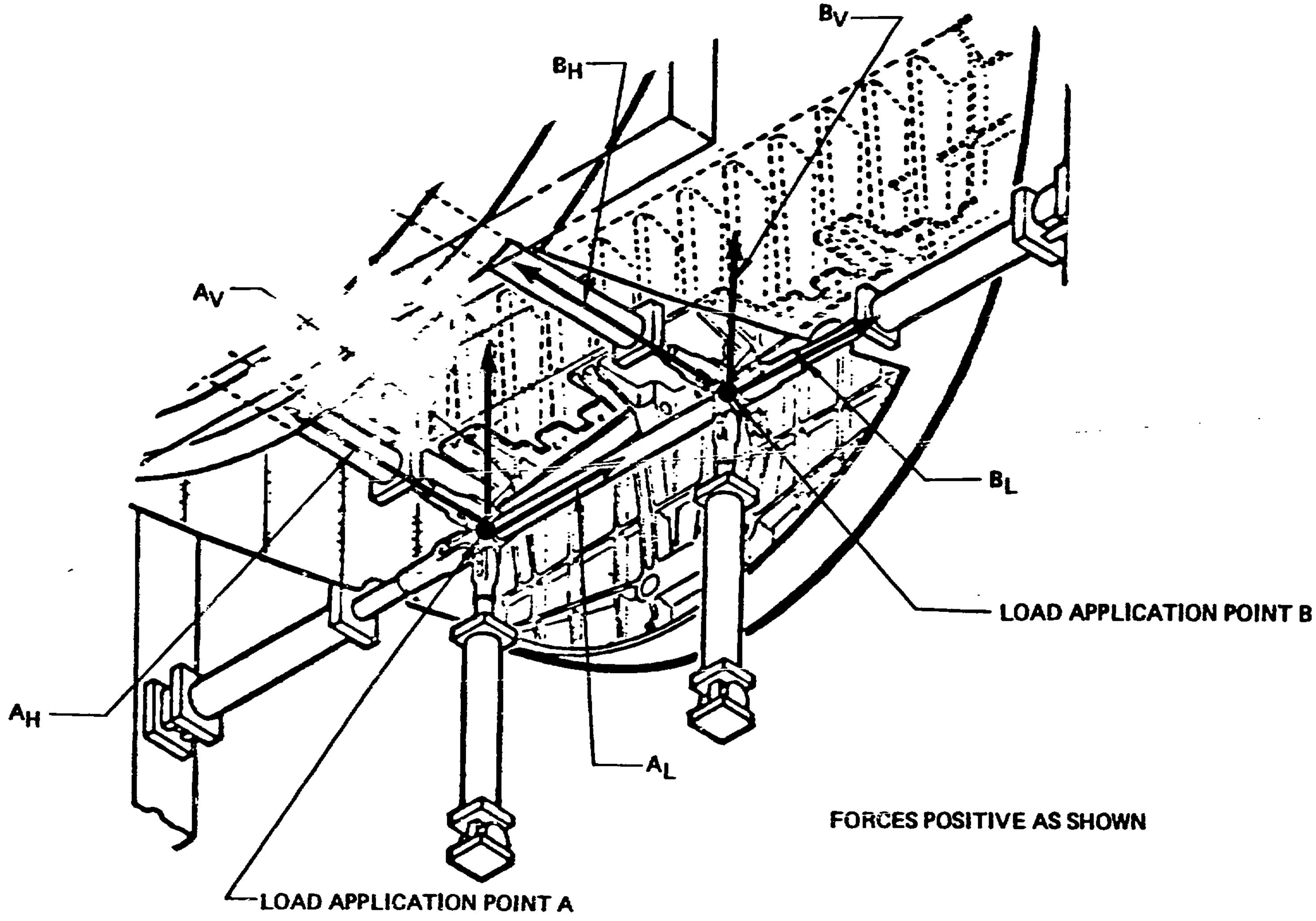

Figure B-1. Test Load Components at Load Application Points

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Table B-1. Test Load Spectrum Block

		Load Point 1*						Load Point 2*						
Flight	Load Level	A_V	A_H	A_L	B_V	B_H	B_L	A_V	A_H	A_L	B_V	B_H	B_L	Cycles
Type 1	T3	0.76	- 8.53	0	0.76	- 8.53	0	1.26	-14.22	0	1.26	-14.22	0	22
	T4	0.66	- 7.39	0	0.66	- 7.39	0	1.36	-15.36	0	1.36	-15.36	0	2
	LCH**													1
	B1	1.01	-11.38	0	1.01	-11.38	0	1.72	-19.43	0	1.72	-19.43	0	5
	B2	1.01	-11.38	0	1.01	-11.38	0	2.44	-27.49	0	2.44	-27.49	0	2
	SL1	0	0	0	0	0	0	12.07	5.41	- 7.20	-12.07	- 5.41	0	1
	SR1	0	0	0	0	0	0	-12.07	- 5.41	0	12.07	5.41	7.20	1
	TL1	1.01	-11.38	0	1.01	-11.38	0	21.12	- 2.36	-12.00	-19.10	-20.39	0	1
	TR1	1.01	-11.38	0	1.01	-11.38	0	-19.10	-20.39	0	21.12	- 2.36	12.00	1
Type 2	T3	.76	- 8.53	0	.76	- 8.53	0	1.26	-14.22	0	1.26	-14.22	0	22
	T4	.66	- 7.39	0	.66	- 7.39	0	1.36	-15.36	0	1.36	-15.36	0	2
	LCH**													1
	B1	1.01	-11.38	0	1.01	-11.38	0	1.72	-19.43	0	1.72	-19.43	0	5
	B2	1.01	-11.38	0	1.01	-11.38	0	2.44	-27.49	0	2.44	-27.49	0	2
	SL1	0	0	0	0	0	0	12.07	5.41	0	-12.07	- 5.41	7.20	1
	SR1	0	0	0	0	0	0	-12.07	- 5.41	- 7.20	12.07	5.41	0	1
	TL1	1.01	-11.38	0	1.01	-11.38	0	21.12	- 2.36	0	-19.10	-20.39	12.00	1
	TR1	1.01	-11.38	0	1.01	-11.38	0	-19.10	-20.39	-12.00	21.12	- 2.36	0	1
Type 2	Repeat													
Type 2	Repeat													
Type 2	Repeat													
Type 3	T3	-1.54	- 7.86	0	-1.54	- 7.86	0	- 2.57	-13.10	0	- 2.57	-13.10	0	44
	T4	-1.34	- 6.81	0	-1.34	- 6.81	0	- 2.78	-14.15	0	- 2.78	-14.15	0	4
	LS**													1
	B1	0.84	- 9.48	0	0.84	- 9.48	0	1.66	-18.72	0	1.66	-18.72	0	5
	B2	0.84	- 9.48	0	0.84	- 9.48	0	2.06	-23.23	0	2.06	-23.23	0	2
	SL1	0	0	0	0	0	0	10.06	4.51	0	-10.06	- 4.51	6.00	1
	SL2	0	0	0	0	0	0	-10.06	- 4.51	- 6.00	10.06	4.51	0	1
	TL1	0.84	- 9.48	0	0.84	- 9.48	0	17.60	- 1.97	0	-15.92	-16.99	10.00	1
	TR1	0.84	- 9.48	0	0.84	- 9.48	0	-15.92	-16.99	-10.00	17.60	- 1.97	0	1
Type 3	Repeat													
Type 3	Repeat													

Table B-1. Test Load Spectrum Block (Concluded)

		Load Point 1*						Load Point 2*						
Flight	Load Level	A_V	A_H	A_L	B_V	B_H	B_L	A_V	A_H	A_L	B_V	B_H	B_L	Cycles
Type 4	T3	0.63	- 7.11	0	0.63	- 7.11	0	1.05	-11.85	0	1.05	-11.85	0	22
	T4	0.55	- 6.16	0	0.55	- 6.16	0	1.13	-12.80	0	1.13	-12.80	0	2
	LCL**													2
	B1	0.84	- 9.48	0	0.84	- 9.48	0	1.66	-18.72	0	1.66	-18.72	0	5
	B2	0.84	- 9.48	0	0.84	- 9.48	0	2.06	-23.23	0	2.06	-23.23	0	2
	SL1	0	0	0	0	0	0	10.06	4.51	0	-10.06	- 4.51	6.00	1
	SR1	0	0	0	0	0	0	-10.06	- 4.51	- 6.00	10.06	4.51	6	1
	TL1	0.84	- 9.48	0	0.84	- 9.48	0	17.60	- 1.97	0	-15.92	-16.99	10.00	1
	TR1	0.48	- 9.48	0	0.84	- 9.48	0	-15.92	-16.99	-10.00	17.60	- 1.97	0	1
Type 4	Repeat													
Type 4	Repeat													
Type 4	Repeat													
Type 4	Repeat													
Type 5	T3	-1.54	- 7.86	0	-1.54	- 7.86	0	- 2.57	-13.10	0	- 2.57	-13.10	0	44
	T4	-1.34	- 6.81	0	-1.34	- 6.81	0	- 2.78	-14.15	0	- 2.78	-14.15	0	4
	LS**													2
	B1	-2.06	-10.48	0	-2.06	-10.48	0	- 4.06	-20.70	0	- 4.06	-20.70	0	5
	B2	-2.06	-10.48	0	-2.06	-10.48	0	- 5.04	-25.68	0	- 5.04	-25.68	0	2
	SL1	0	0	0	0	0	0	10.06	4.51	0	-10.06	- 4.51	6.00	1
	SR1	0	0	0	0	0	0	-10.06	- 4.51	- 6.00	10.06	4.51	0	1
	TL1	0.84	- 9.48	0	0.84	- 9.48	0	17.60	- 1.97	0	-15.92	-16.99	10.00	1
	TR1	0.84	- 9.48	0	0.84	- 9.48	0	-15.92	-16.99	-10.00	17.60	- 1.97	0	1
Type 5	Repeat													
Type 5	Repeat													

* Loads are in kips

** Landing Conditions LCH - See Table B-2
LCL - See Table B-3
LS - See Table B-4

Table B-2. Load Points for CTOL Landing Conditions (GW=162 kips)

	Load Point 1*						Load Point 2*						Load Point 3*						
Load Level	A_V	A_H	A_L	B_V	B_H	B_L	A_V	A_H	A_L	B_V	B_H	B_L	A_V	A_H	A_L	B_V	B_H	B_L	Occurrences
LCH1.1	0	0	0	0	0	0	-11.16	-15.58	0	-11.16	-15.58	0	7.09	- 9.28	0	7.09	- 9.28	0	312
LCH1.2	0	0	0	0	0	0	13.08	- 5.97	- 7.20	-11.06	-16.78	0	0	0	0	0	0	0	80
LCH1.3	0	0	0	0	0	0	-11.06	-16.78	0	13.08	- 5.97	7.20	0	0	0	0	0	0	80
LCH2.1	0	0	0	0	0	0	-12.55	-17.52	0	-12.55	-17.52	0	8.01	-10.42	0	8.01	-10.42	0	174
LCH2.2	0	0	0	0	0	0	14.71	- 6.71	- 8.10	-12.44	-18.88	0	0	0	0	0	0	0	42
LCH2.3	0	0	0	0	0	0	-12.44	-18.88	0	14.71	- 6.71	0	0	0	0	0	0	0	42
LCH3.1	0	0	0	0	0	0	-16.73	-23.36	0	-16.73	-23.36	0	10.63	-13.91	0	10.63	-13.91	0	104
LCH3.2	0	0	0	0	0	0	19.61	- 8.95	-10.80	-16.59	-25.17	0	0	0	0	0	0	0	26
LCH3.3	0	0	0	0	0	0	-16.59	-25.17	0	19.61	- 8.95	10.80	0	0	0	0	0	0	26
LCH4.1	0	0	0	0	0	0	-20.92	-29.21	0	-20.92	-29.21	0	13.33	-17.38	0	13.33	-17.38	0	52
LCH4.2	0	0	0	0	0	0	24.52	-11.19	-13.50	-20.74	-31.47	0	0	0	0	0	0	0	12
LCH4.3	0	0	0	0	0	0	-20.74	-31.47	0	24.52	-11.19	13.50	0	0	0	0	0	0	12
LCH5.1	0	0	0	0	0	0	-25.10	-35.05	0	-25.10	-35.05	0	15.95	-20.87	0	15.95	-20.87	0	18
LCH5.2	0	0	0	0	0	0	29.42	-13.43	-16.20	-24.88	-37.76	0	0	0	0	0	0	0	4
LCH5.3	0	0	0	0	0	0	-24.88	-37.76	0	29.42	-13.43	16.20	0	0	0	0	0	0	4
LCH6.1	0	0	0	0	0	0	-29.28	-40.89	0	-29.28	-40.89	0	18.65	-24.34	0	18.65	-24.34	0	4
LCH6.2	0	0	0	0	0	0	34.32	-15.67	-18.90	-29.03	-44.05	0	0	0	0	0	0	0	2
LCH6.3	0	0	0	0	0	0	-29.03	-44.05	0	34.32	-15.67	18.70	0	0	0	0	0	0	2
LCH7.1	0	0	0	0	0	0	-33.47	-46.72	0	-33.47	-46.72	0	21.27	-27.82	0	21.27	-27.82	0	2
LCH8.1	0	0	0	0	0	0	-37.65	-52.57	0	-37.65	-52.57	0	23.96	-31.29	0	23.96	-31.29	0	2

* Loads are in kips

Table B-3. Load Points for CTOL Landing Conditions (GW=136 kips)

	Load Point 1*						Load Point 2*						Load Point 3*						
Load Level	A_V	A_H	A_L	B_V	B_H	B_L	A_V	A_H	A_L	B_V	B_H	B_L	A_V	A_H	A_L	B_V	B_H	B_L	Occurrences
LCL1.1	0	0	0	0	0	0	- 9.30	-12.98	0	- 9.30	-12.98	0	5.91	- 7.73	0	5.91	- 7.73	0	624
LCL1.2	0	0	0	0	0	0	10.90	- 4.97	- 6.00	- 9.22	-13.99	0	0	0	0	0	0	0	158
LCL1.3	0	0	0	0	0	0	- 9.22	-13.99	0	10.90	- 4.97	6.00	0	0	0	0	0	0	158
LCL2.1	0	0	0	0	0	0	-12.55	-17.52	0	-12.55	-17.52	0	8.01	-10.42	0	8.01	-10.42	0	348
LCL2.2	0	0	0	0	0	0	14.71	- 6.71	- 8.10	-12.44	-18.88	0	0	0	0	0	0	0	86
LCL2.3	0	0	0	0	0	0	-12.44	-18.88	0	14.71	- 6.71	8.10	0	0	0	0	0	0	86
LCL3.1	0	0	0	0	0	0	-16.73	-23.36	0	-16.73	-23.36	0	10.63	-13.91	0	10.63	-13.91	0	206
LCL3.2	0	0	0	0	0	0	19.61	- 8.95	-10.80	-16.59	-25.17	0	0	0	0	0	0	0	52
LCL3.3	0	0	0	0	0	0	-16.59	-25.17	0	19.61	- 8.95	10.80	0	0	0	0	0	0	52
LCL4.1	0	0	0	0	0	0	-20.92	-29.21	0	-20.92	-29.21	0	13.33	-17.38	0	13.33	-17.38	0	104
LCL4.2	0	0	0	0	0	0	24.52	-11.19	-13.50	-20.74	-31.47	0	0	0	0	0	0	0	26
LCL4.3	0	0	0	0	0	0	-20.74	-31.47	0	24.52	-11.19	13.50	0	0	0	0	0	0	26
LCL5.1	0	0	0	0	0	0	-25.10	-35.05	0	-25.10	-35.05	0	15.95	-20.87	0	15.95	-20.87	0	36
LCL5.2	0	0	0	0	0	0	29.42	-13.43	-16.20	-24.88	-37.76	0	0	0	0	0	0	0	8
LCL5.3	0	0	0	0	0	0	-24.88	-37.76	0	29.42	-13.43	16.20	0	0	0	0	0	0	8
LCL6.1	0	0	0	0	0	0	-29.28	-40.89	0	-29.28	-40.89	0	18.65	-24.34	0	18.65	-24.34	0	12
LCL6.2	0	0	0	0	0	0	34.32	-15.67	-18.90	-29.03	-44.05	0	0	0	0	0	0	0	3
LCL6.3	0	0	0	0	0	0	-29.03	-44.05	0	34.32	-15.67	18.90	0	0	0	0	0	0	2
LCL7.1	0	0	0	0	0	0	-33.47	-47.62	0	-33.47	-47.62	0	21.27	-27.82	0	21.27	-27.82	0	3
LCL8.1	0	0	0	0	0	0	-37.65	-52.57	0	-37.65	-52.57	0	23.96	-31.29	0	23.96	-31.29	0	2

*Loads are in kips

Table B-4. Load Points for STOL Landing Conditions

Load Level	Load Point 1*						Load Point 2*						Load Point 3*						Occurrences
	A_V	A_H	A_L	B_V	B_H	B_L	A_V	A_H	A_L	B_V	B_H	B_L	A_V	A_H	A_L	B_V	B_H	B_L	
LS1.1	0	0	0	0	0	0	- 9.30	-12.98	0	- 9.30	-12.98	0	5.91	- 7.73	0	5.91	- 7.73	0	16
LS1.2	0	0	0	0	0	0	10.90	- 4.97	- 6.00	- 9.22	-13.99	0	0	0	0	0	0	0	4
LS1.3	0	0	0	0	0	0	- 9.22	-13.99	0	10.90	- 4.97	6.00	0	0	0	0	0	0	4
LS2.1	0	0	0	0	0	0	-12.55	-17.52	0	-12.55	-17.52	0	8.01	-10.42	0	8.01	-10.42	0	44
LS2.2	0	0	0	0	0	0	14.71	- 6.71	- 8.10	-12.44	-18.88	0	0	0	0	0	0	0	12
LS2.3	0	0	0	0	0	0	-12.44	-18.88	0	14.71	- 6.71	8.10	0	0	0	0	0	0	12
LS3.1	0	0	0	0	0	0	-16.73	-23.36	0	-16.73	-23.36	0	10.63	-13.91	0	10.63	-13.91	0	98
LS3.2	0	0	0	0	0	0	19.61	- 8.96	-10.80	-16.59	-25.17	0	0	0	0	0	0	0	24
LS3.3	0	0	0	0	0	0	-16.59	-25.17	0	19.61	- 8.96	10.80	0	0	0	0	0	0	24
LS4.1	0	0	0	0	0	0	-20.92	-29.21	0	-20.92	-29.21	0	13.33	-17.38	0	13.33	-17.38	0	116
LS4.2	0	0	0	0	0	0	24.52	-11.19	-13.50	-20.74	-31.47	0	0	0	0	0	0	0	28
LS4.3	0	0	0	0	0	0	-20.74	-31.47	0	24.52	-11.19	13.50	0	0	0	0	0	0	28
LS5.1	0	0	0	0	0	0	-25.10	-35.05	0	-25.10	-35.05	0	15.95	-20.87	0	15.95	-20.87	0	112
LS5.2	0	0	0	0	0	0	29.42	-13.43	-16.20	-24.88	-37.76	0	0	0	0	0	0	0	28
LS5.3	0	0	0	0	0	0	-24.88	-37.76	0	29.42	-13.43	16.20	0	0	0	0	0	0	28
LS6.1	0	0	0	0	0	0	-29.28	-40.89	0	-29.28	-40.89	0	18.65	-24.34	0	18.65	-24.34	0	106
LS6.2	0	0	0	0	0	0	34.32	-15.67	-18.90	-29.03	-44.05	0	0	0	0	0	0	0	26
LS6.3	0	0	0	0	0	0	-29.03	-44.05	0	34.32	-15.67	18.90	0	0	0	0	0	0	26
LS7.1	0	0	0	0	0	0	-33.47	-47.62	0	-33.47	-47.62	0	21.27	-27.82	0	21.27	-27.82	0	72
LS7.2	0	0	0	0	0	0	38.23	-17.91	-21.60	-33.18	-50.35	0	0	0	0	0	0	0	18
LS7.3	0	0	0	0	0	0	-33.18	-50.35	0	38.23	-17.91	21.60	0	0	0	0	0	0	18
LS8.1	0	0	0	0	0	0	-37.65	-52.57	0	-37.65	-52.57	0	23.96	-31.29	0	23.96	-31.29	0	46
LS8.2	0	0	0	0	0	0	44.13	-20.14	-24.30	-37.32	-56.64	0	0	0	0	0	0	0	10
LS8.3	0	0	0	0	0	0	-37.32	-56.64	0	44.13	-20.14	24.30	0	0	0	0	0	0	10
LS9.1	0	0	0	0	0	0	-41.37	-57.76	0	-41.37	-57.76	0	26.33	-34.39	0	26.33	-34.39	0	28
LS9.2	0	0	0	0	0	0	48.49	-22.13	-26.70	-41.01	-62.24	0	0	0	0	0	0	0	8
LS9.3	0	0	0	0	0	0	-41.01	-62.24	0	48.49	-22.13	26.70	0	0	0	0	0	0	8
LS10.1	0	0	0	0	0	0	-46.02	-64.25	0	-46.02	-64.25	0	26.75	-39.13	0	26.75	-39.13	0	14
LS10.2	0	0	0	0	0	0	52.38	- 1.17	-30.00	-48.18	-46.23	0	0	0	0	0	0	0	4
LS10.3	0	0	0	0	0	0	-48.18	-46.23	0	52.38	- 1.17	30.00	0	0	0	0	0	0	4
LS11.1	0	0	0	0	0	0	-50.20	-70.09	0	-50.20	-70.09	0	31.90	-41.74	0	31.90	-41.74	0	10
LS11.2	0	0	0	0	0	0	52.38	- 1.17	-30.00	-48.18	-46.23	0	0	0	0	0	0	0	2
LS11.3	0	0	0	0	0	0	-48.18	-46.23	0	52.38	- 1.17	30.00	0	0	0	0	0	0	2
LS12.1	0	0	0	0	0	0	-54.38	-75.93	0	-54.38	-75.93	0	34.60	-45.21	0	34.60	-45.21	0	2
LS12.2	0	0	0	0	0	0	52.38	- 1.17	-30.00	-48.18	-46.23	0	0	0	0	0	0	0	2
LS12.3	0	0	0	0	0	0	-48.18	-46.23	0	52.38	- 1.17	30.00	0	0	0	0	0	0	2
LS13.1	0	0	0	0	0	0	-59.03	-82.42	0	-59.03	-82.42	0	37.55	-49.07	0	37.55	-49.07	0	2
LS14.1	0	0	0	0	0	0	-62.75	-87.62	0	-62.75	-87.62	0	39.92	-52.17	0	39.92	-52.17	0	2

* Loads are in kips

APPENDIX C

STRAIN GAGE DATA FROM DAMAGE TOLERANCE TEST II

Table C-1. Bulkhead Strain Gage R1 Springback Landing

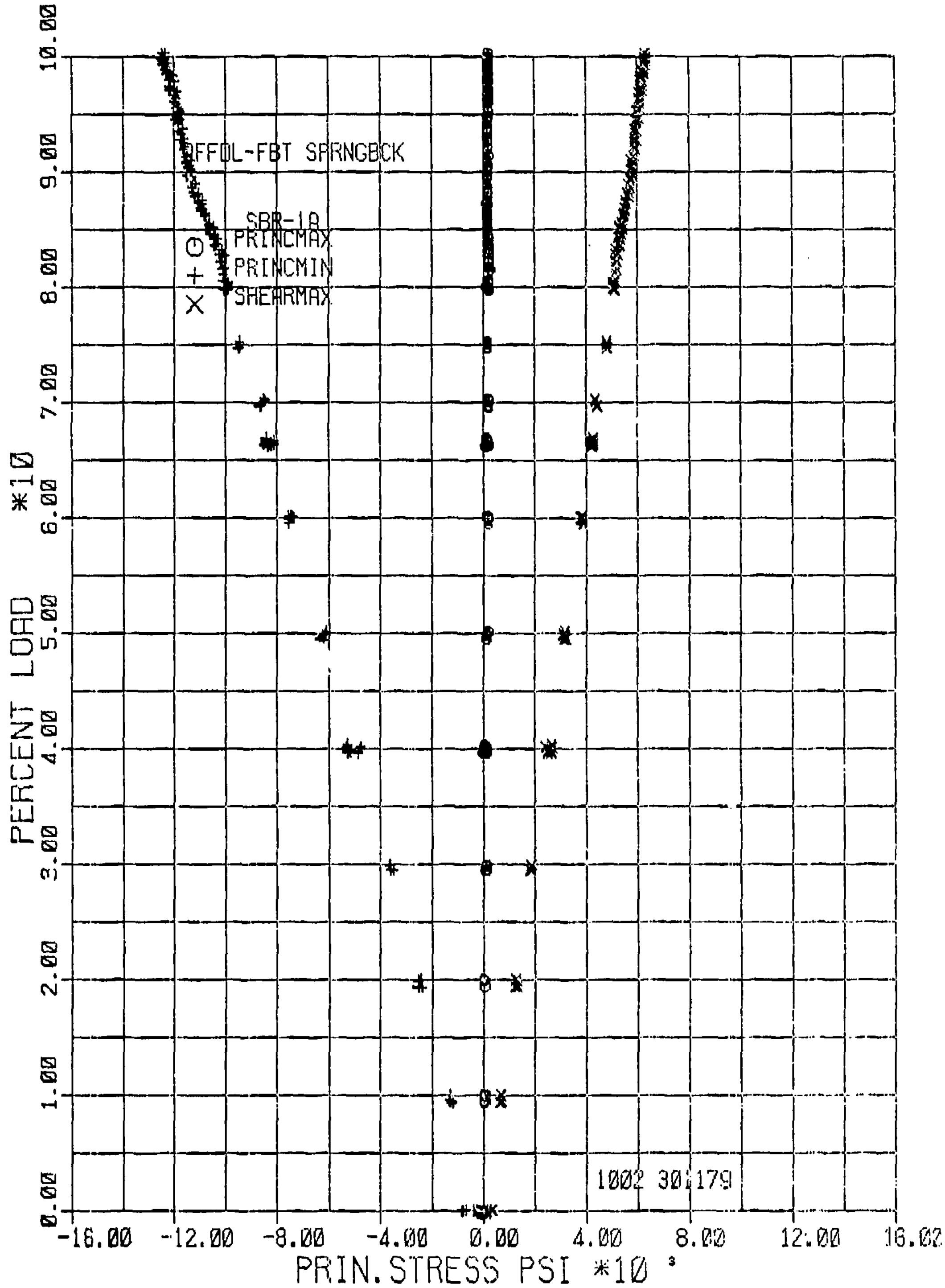

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Table C-2. Bulkhead Strain Gage R2 Springback Landing

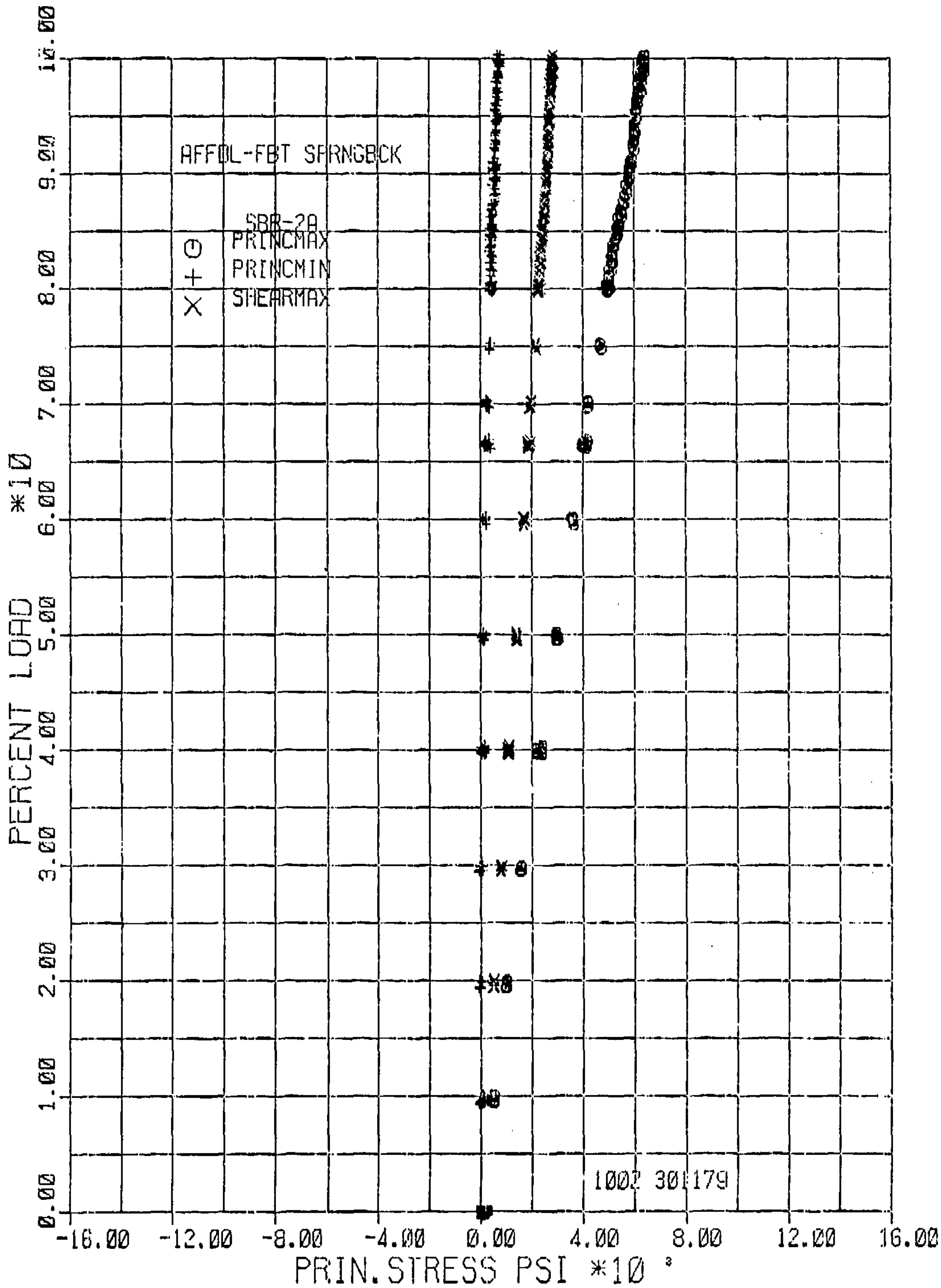


Table C-3. Bulkhead Strain Gage R3 Springback Landing

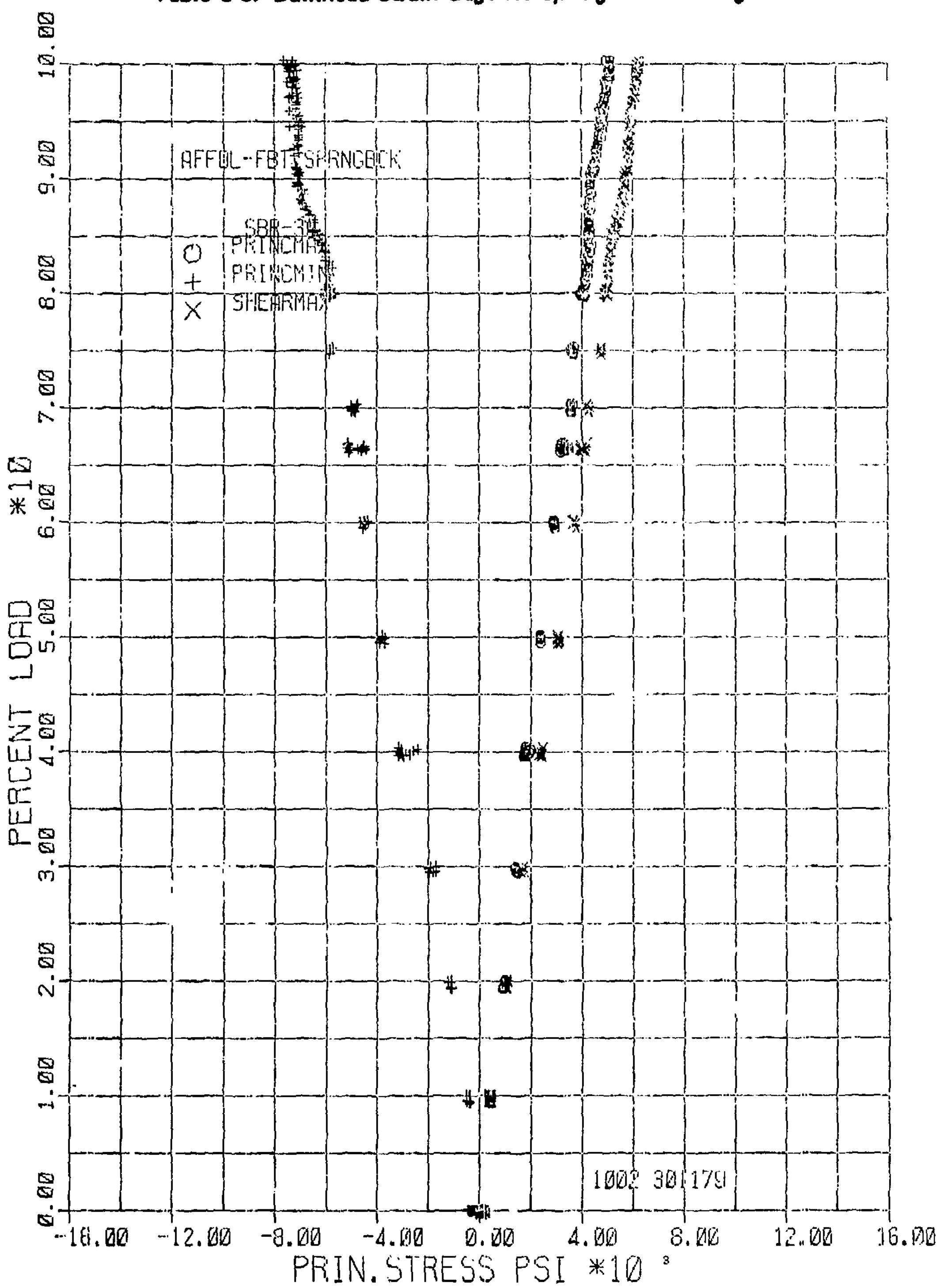


Table C-4. Bulkhead Strain Gage R4 Springback Landing

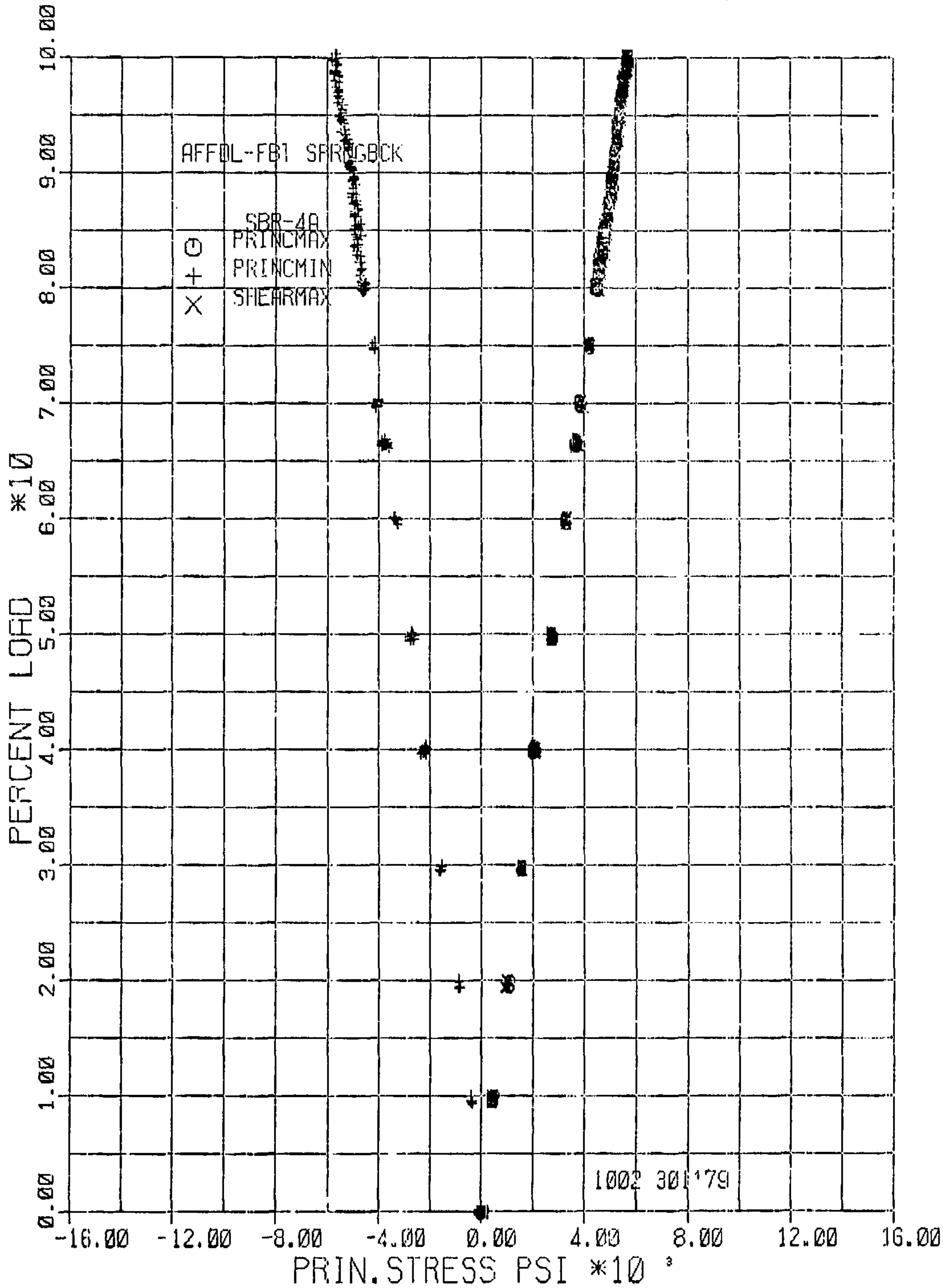


Table C-5. Bulkhead Strain Gage R5 Springback Landing

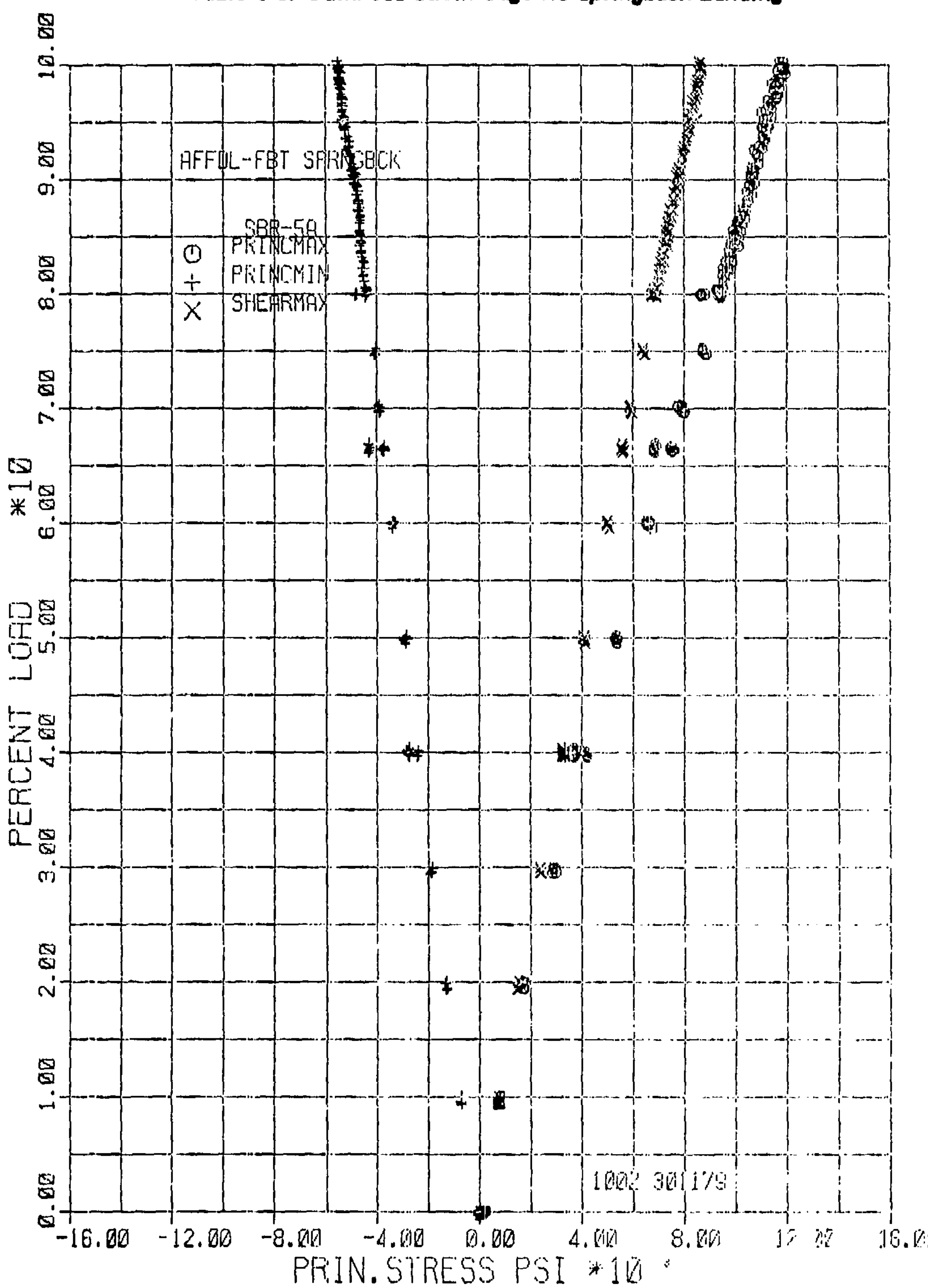


Table C-6. Bulkhead Strain Gage R7 Springback Landing

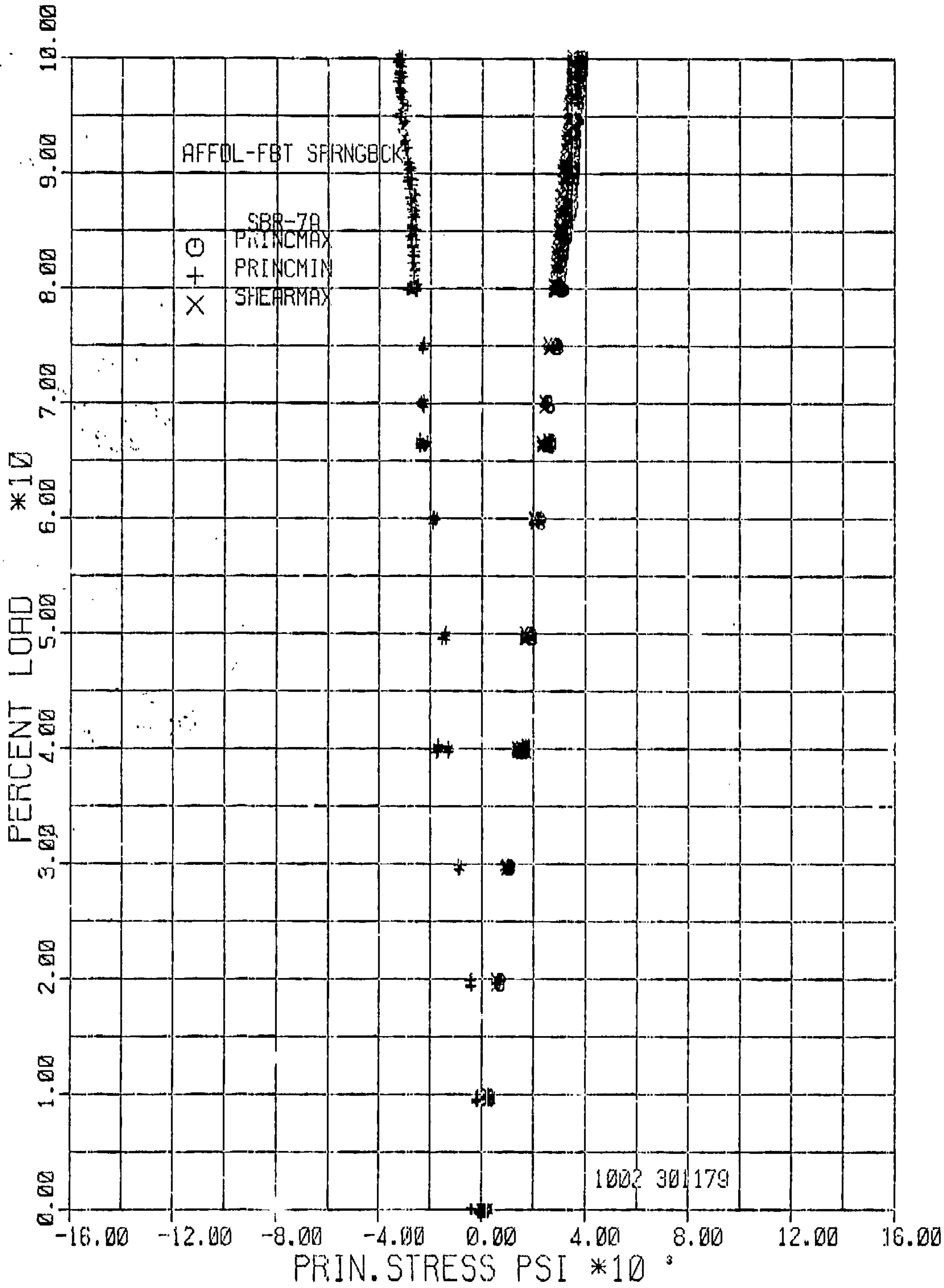


Table C-7. Bulkhead Strain Gage R8 Springback Landing

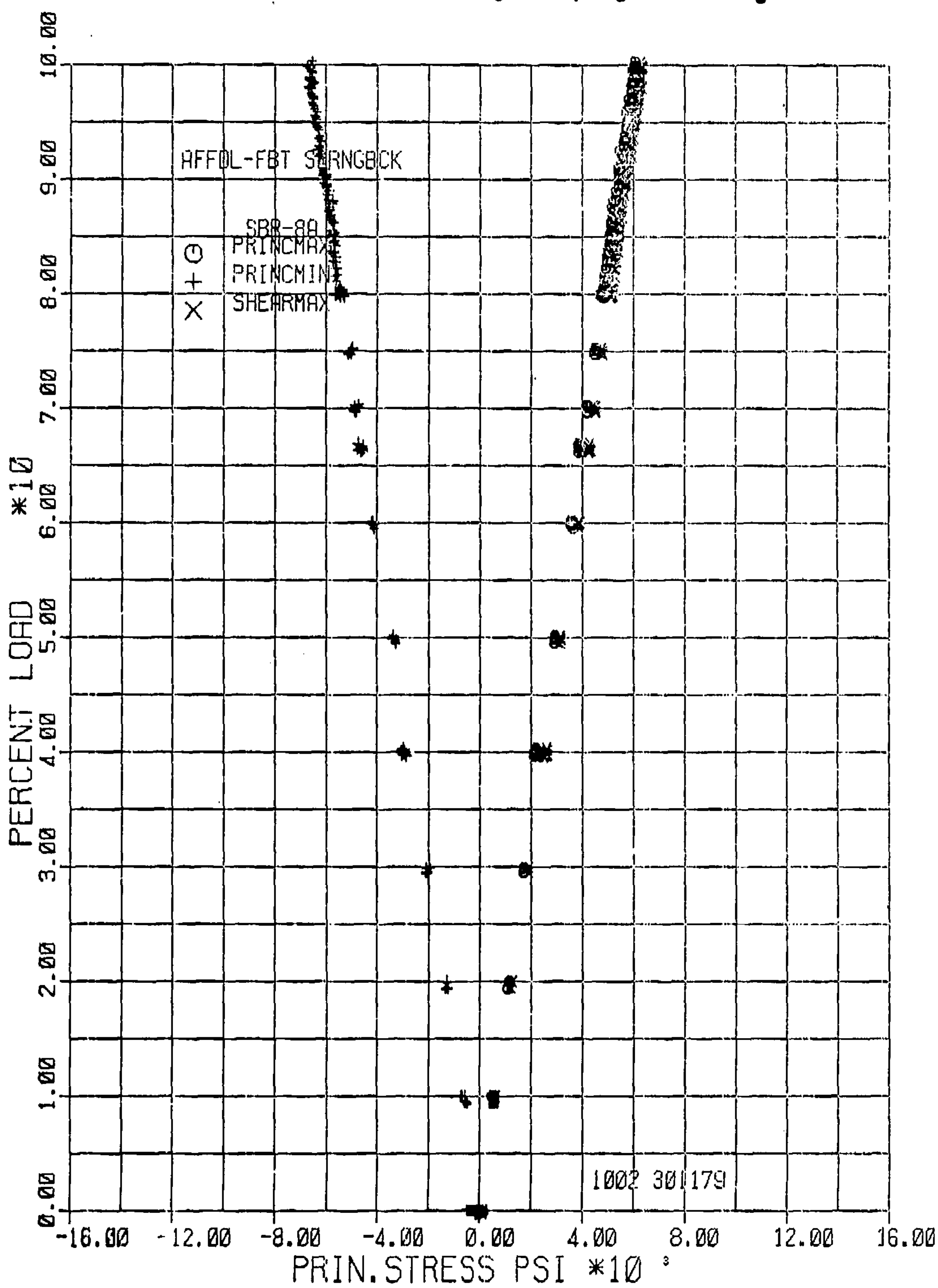


Table C-8. Bulkhead Strain Gage R9 Springback Landing

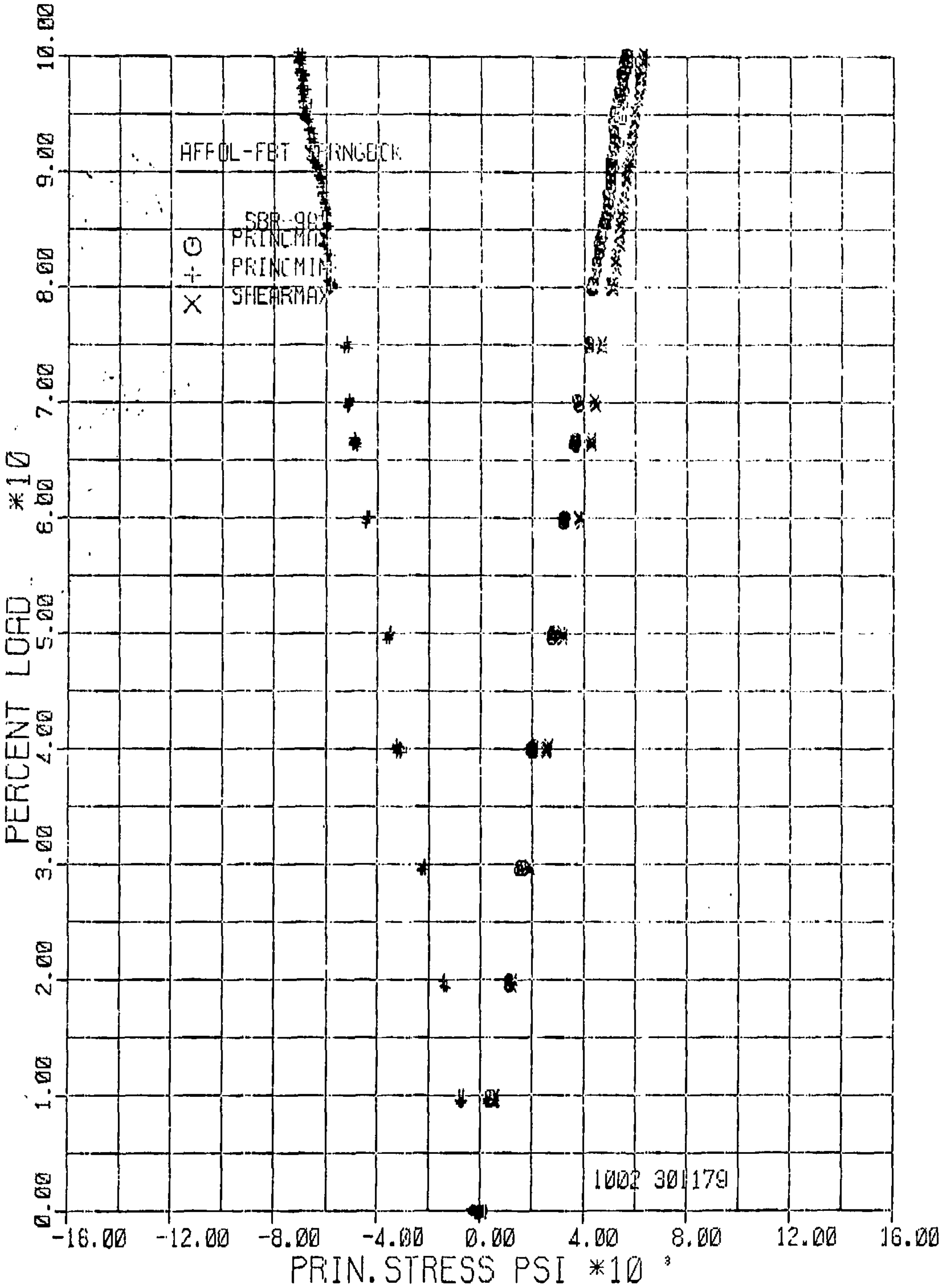


Table C-9. Bulkhead Strain Gage R10 Springback Landing

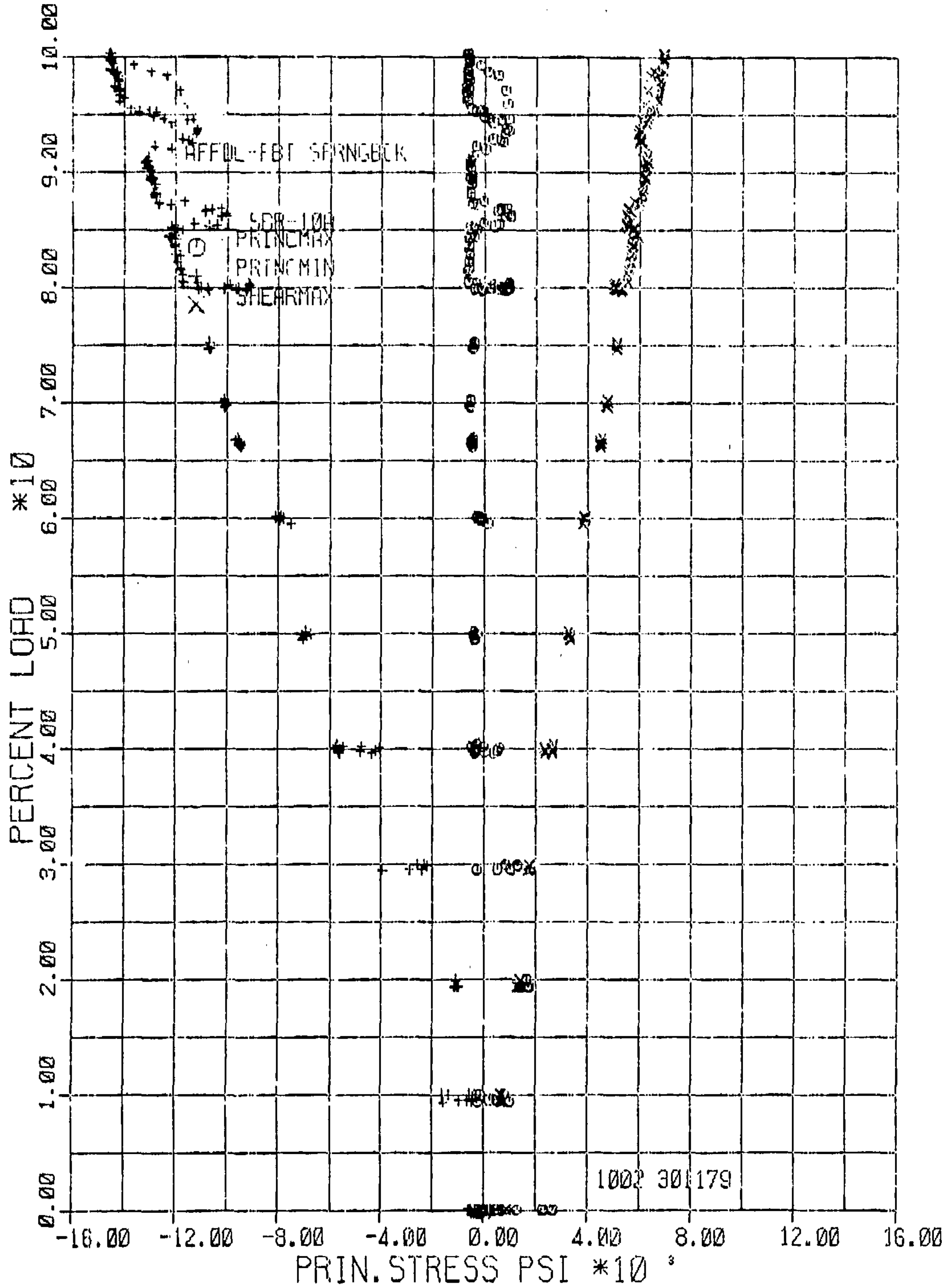


Table C-10. Bulkhead Strain Gage R11 Springback Landing

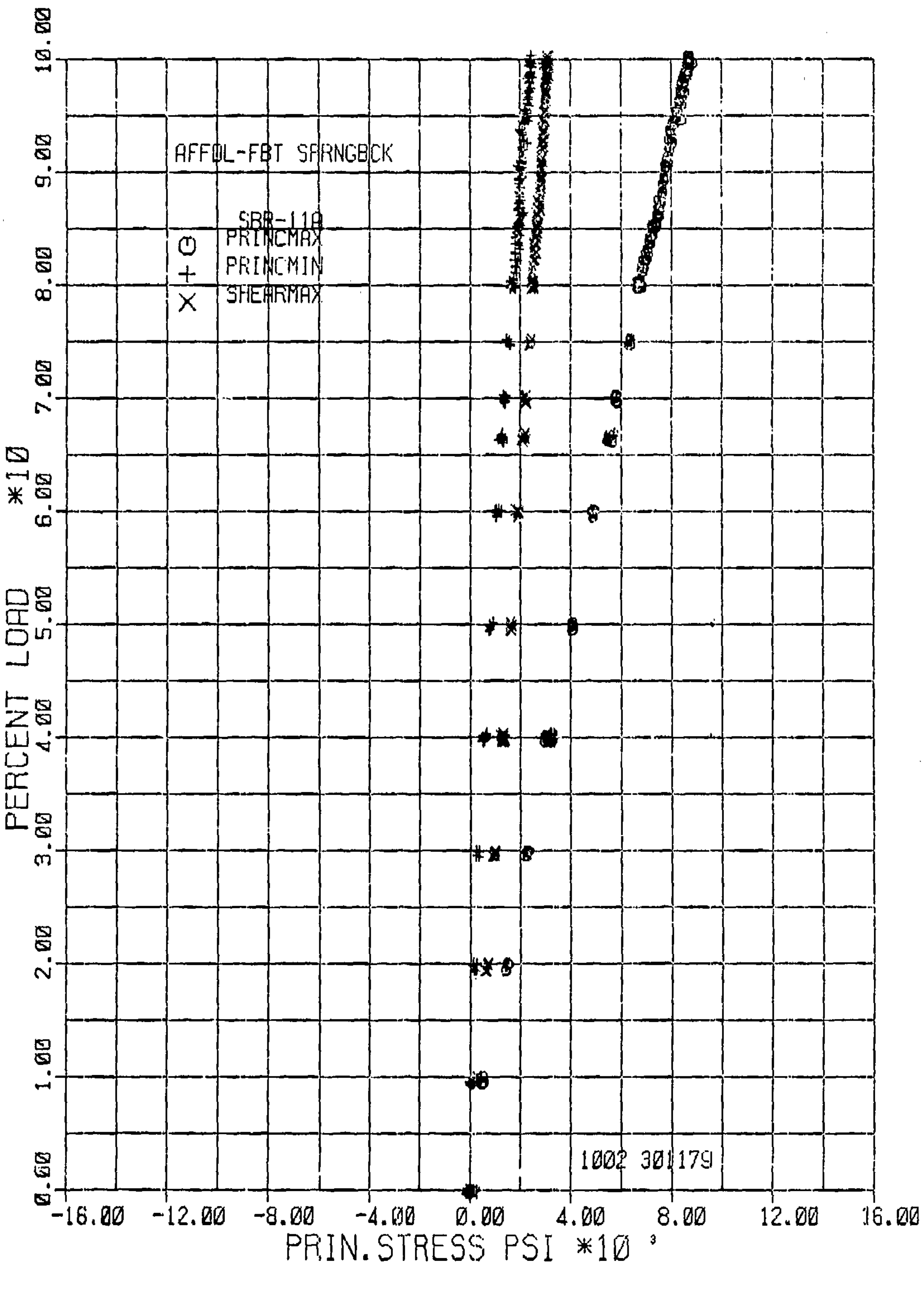


Table C-11. Bulkhead Strain Gage R12 Springback Landing

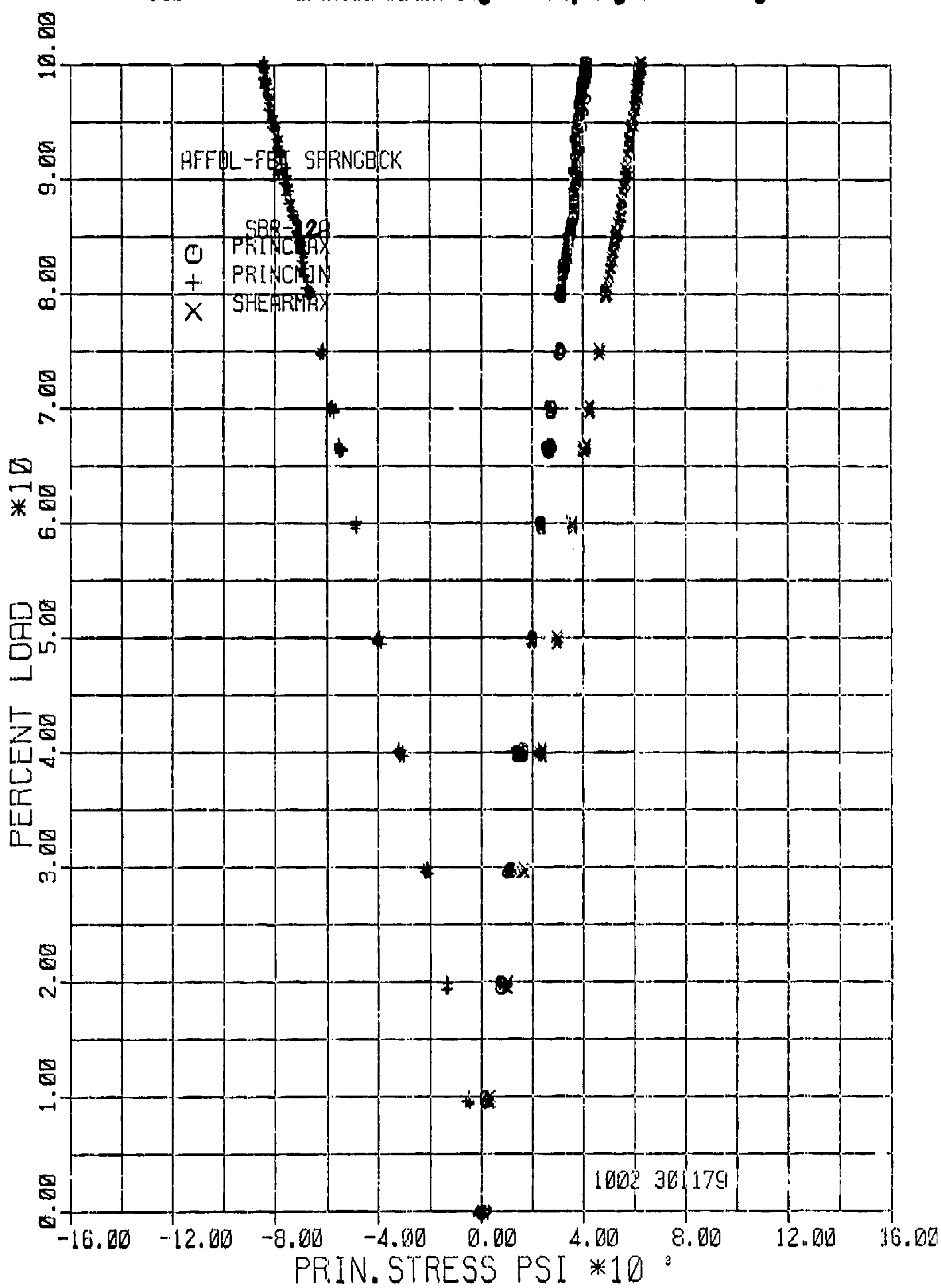


Table C-12. Bulkhead Strain Gage R 3 Springback Landing

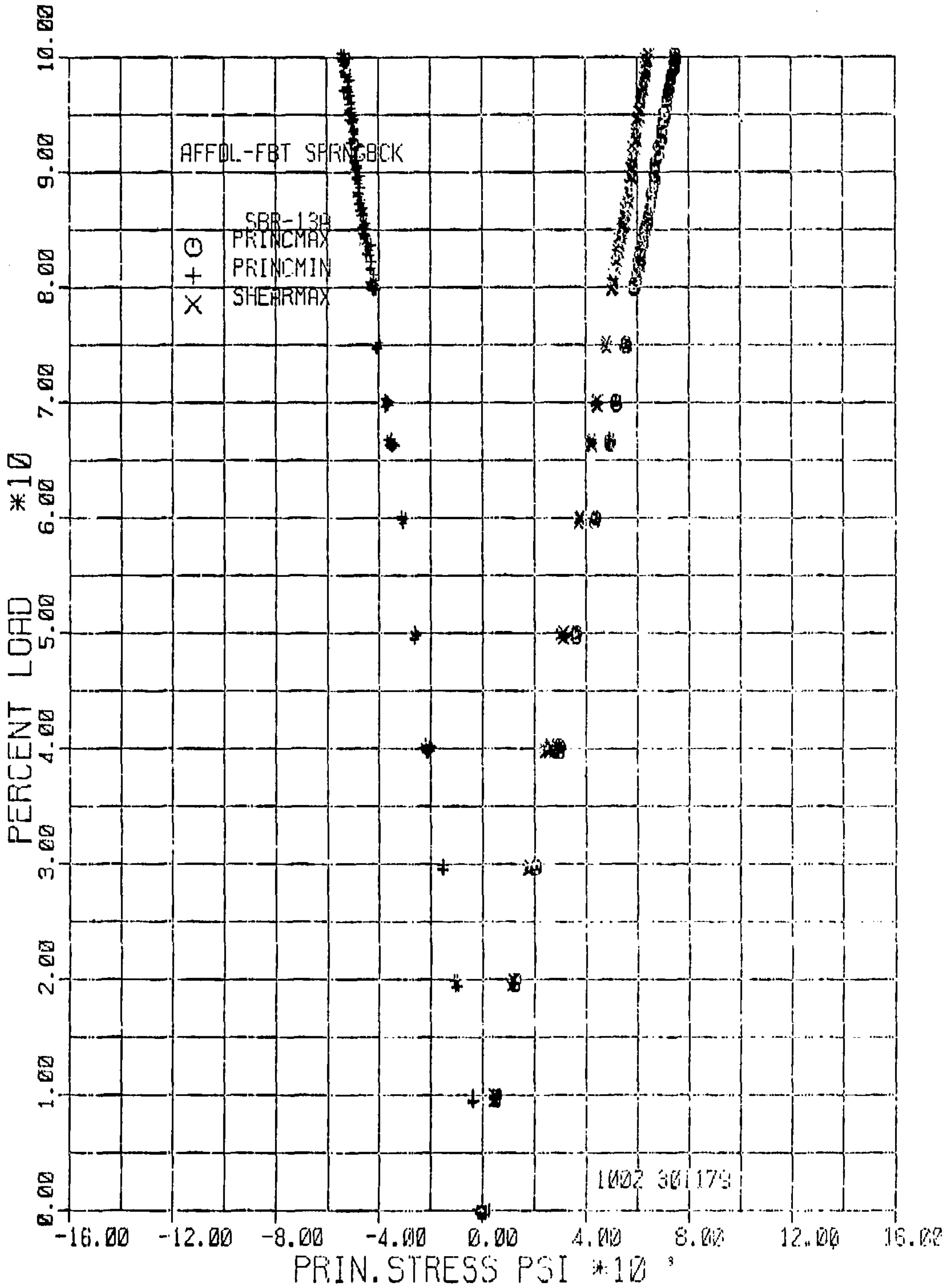


Table C-13. Bulkhead Strain Gage R15 Springback Landing

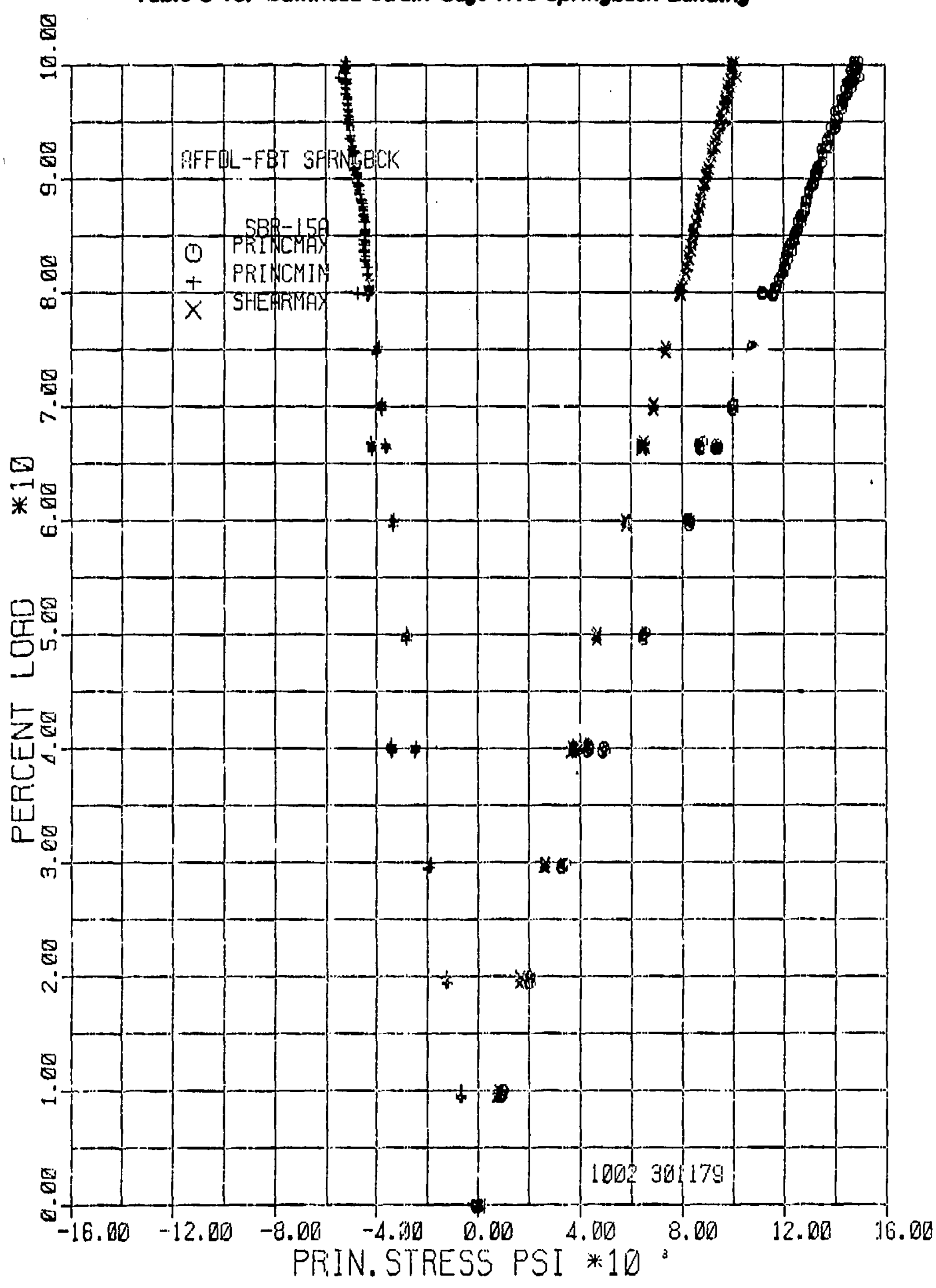


Table C-14. Bulkhead Strain Gage R16 Springback Landing

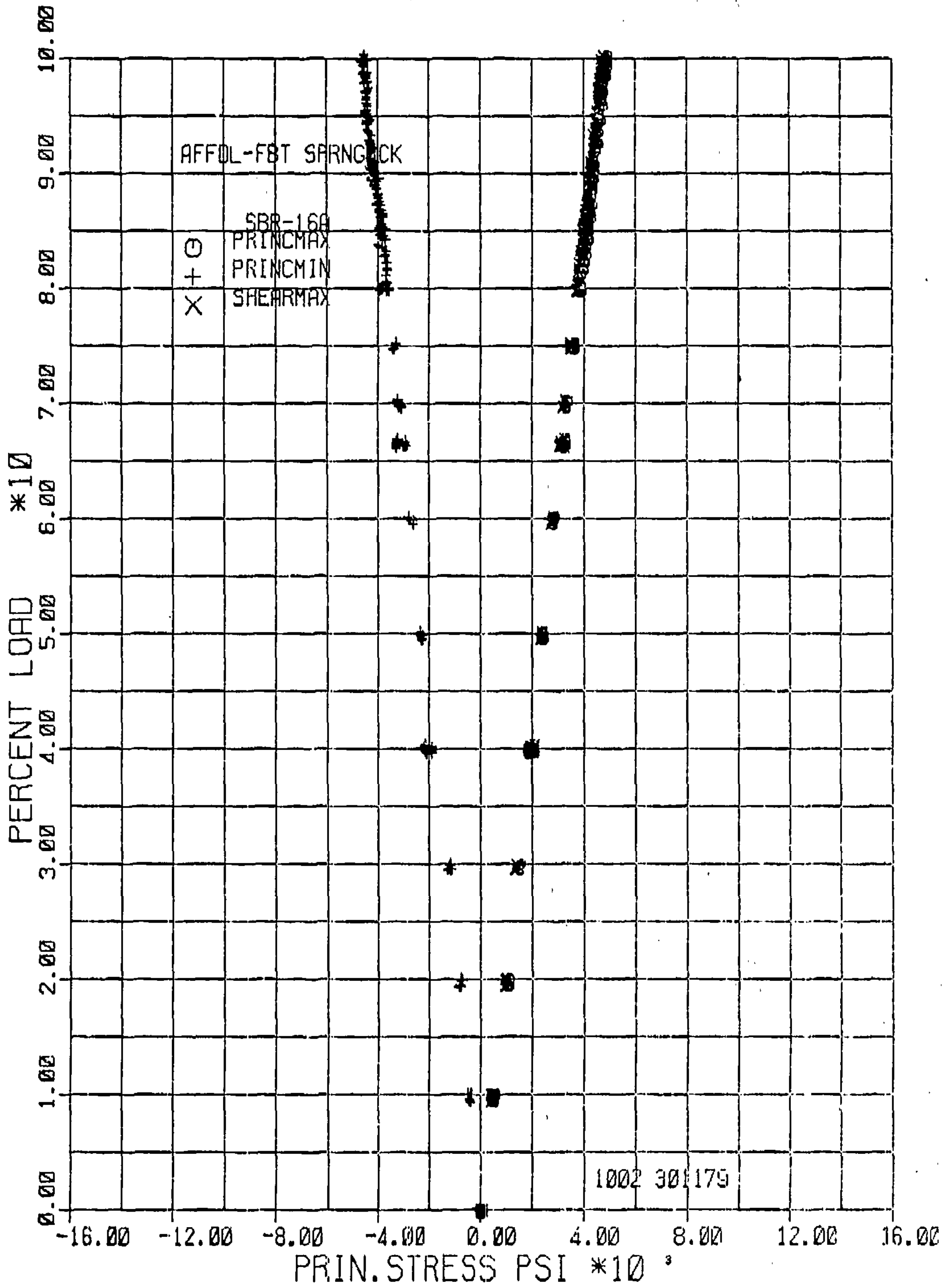


Table C-15. Bulkhead Strain Gage R17 Springback Landing

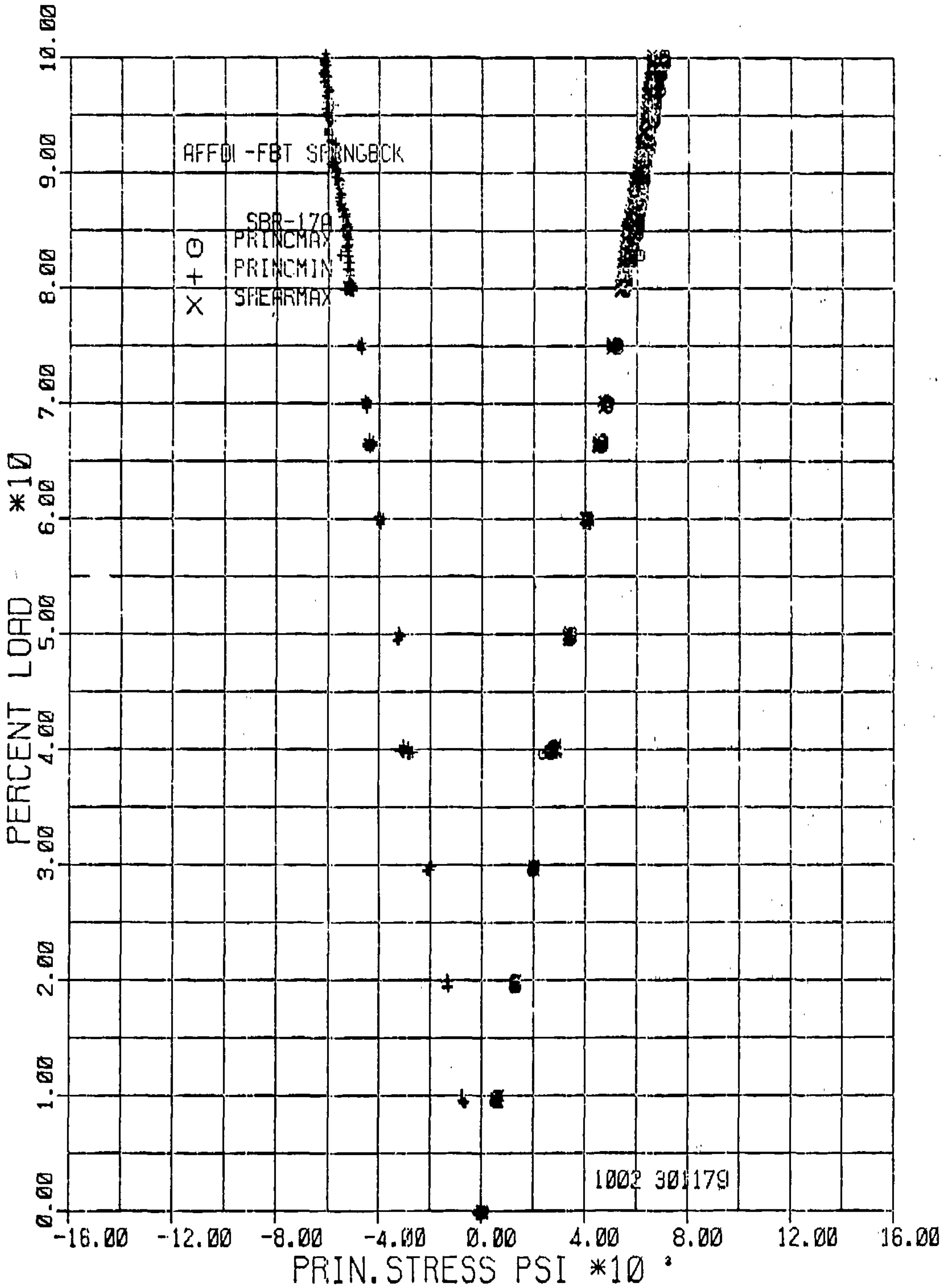


Table C-16. Bulkhead Strain Gage R18 Springback Landing

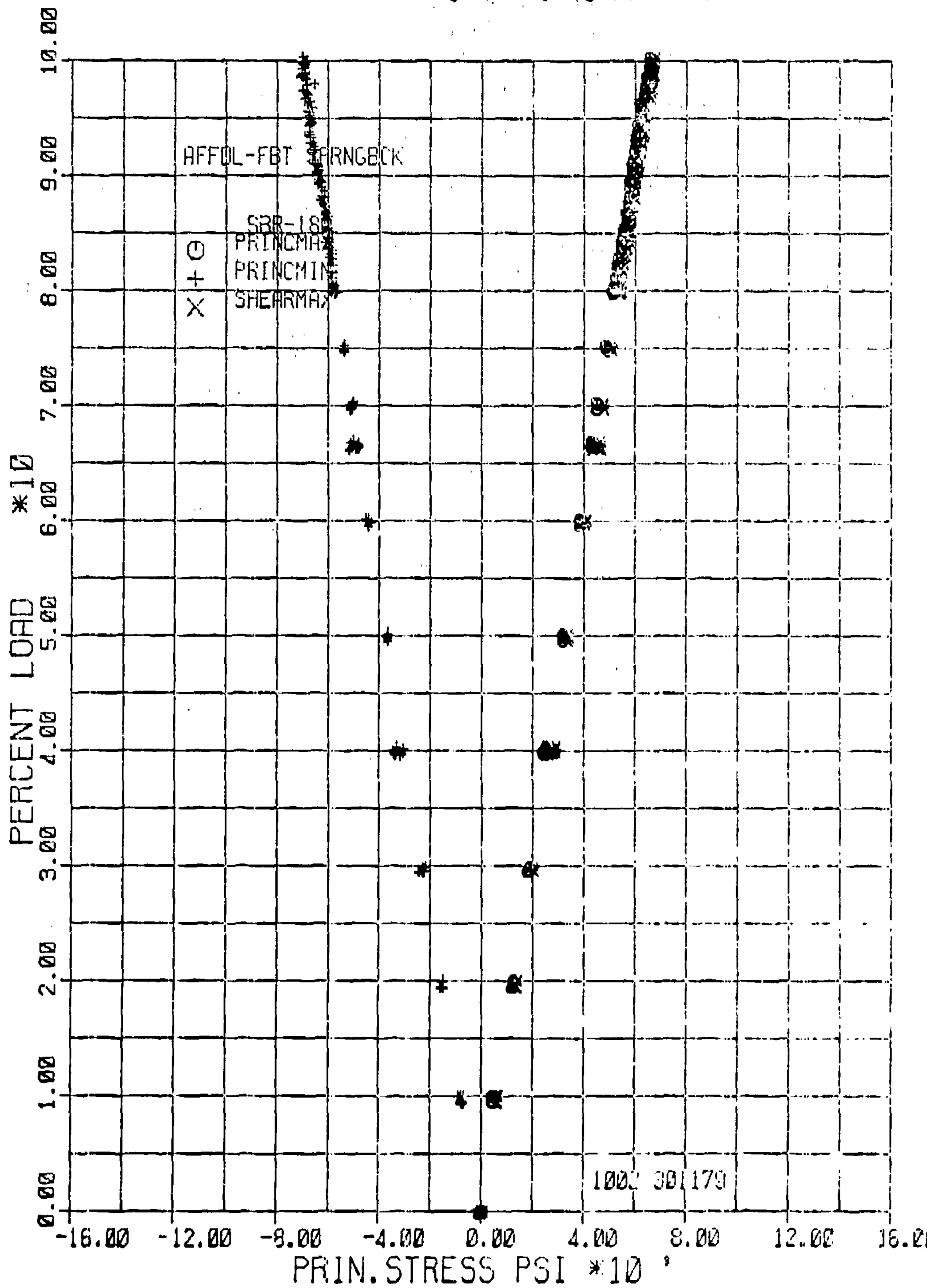


Table C-17. Bulkhead Strain Gage R20 Springback Landing

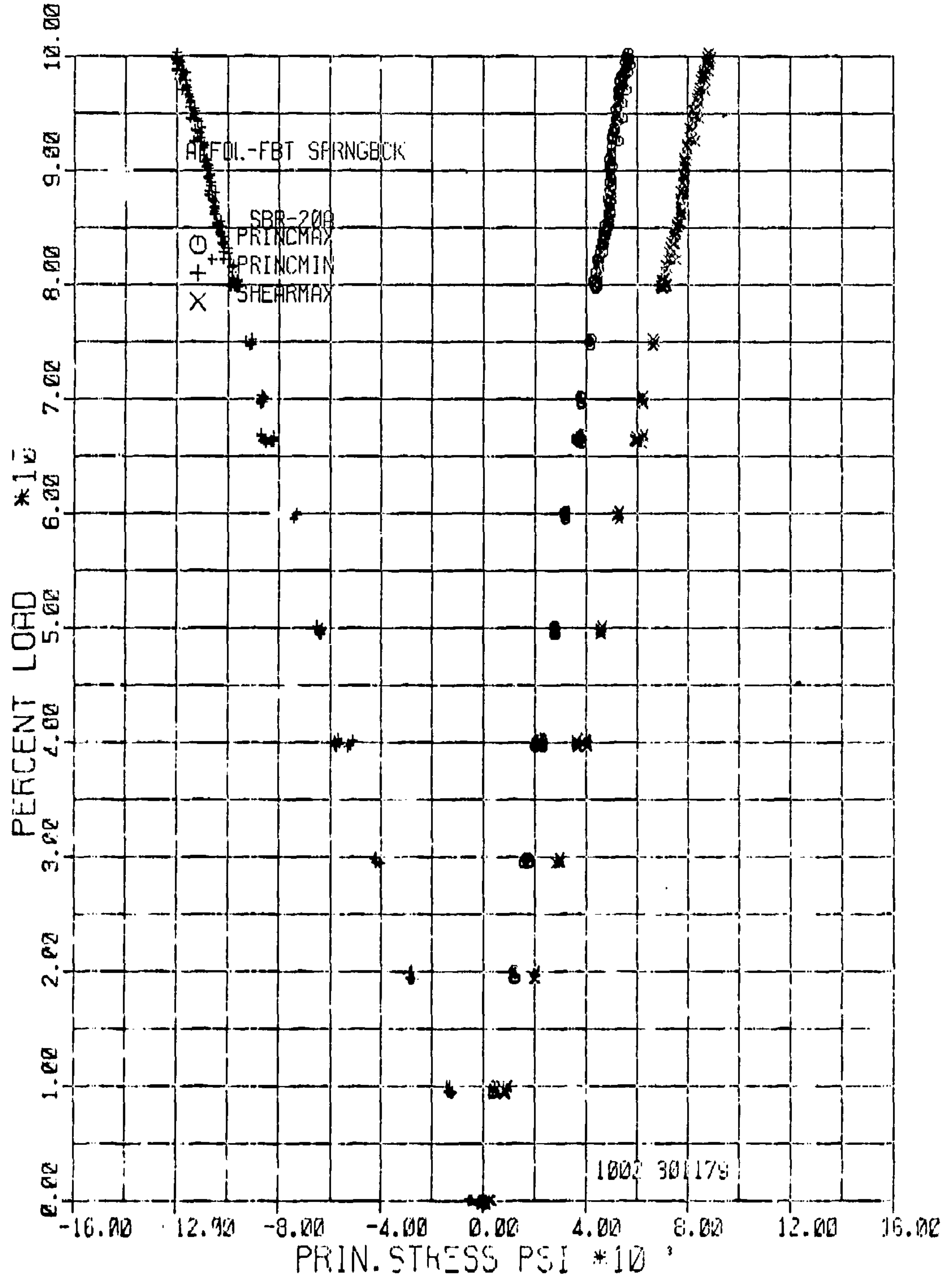


Table C-18. Bulkhead Strain Gage R21 Springback Landing

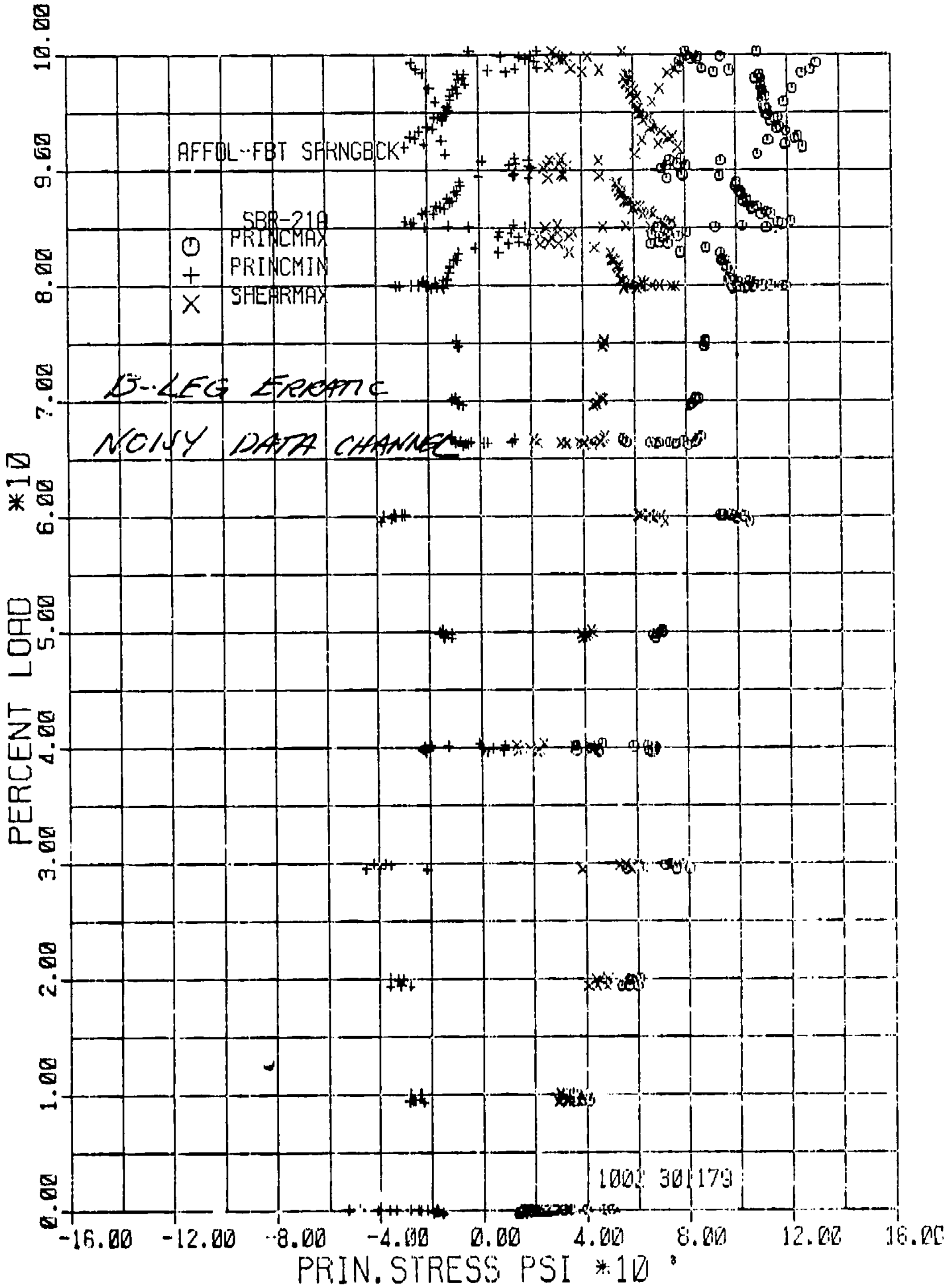


Table C-19. Bulkhead Strain Gage R25 Springback Landing

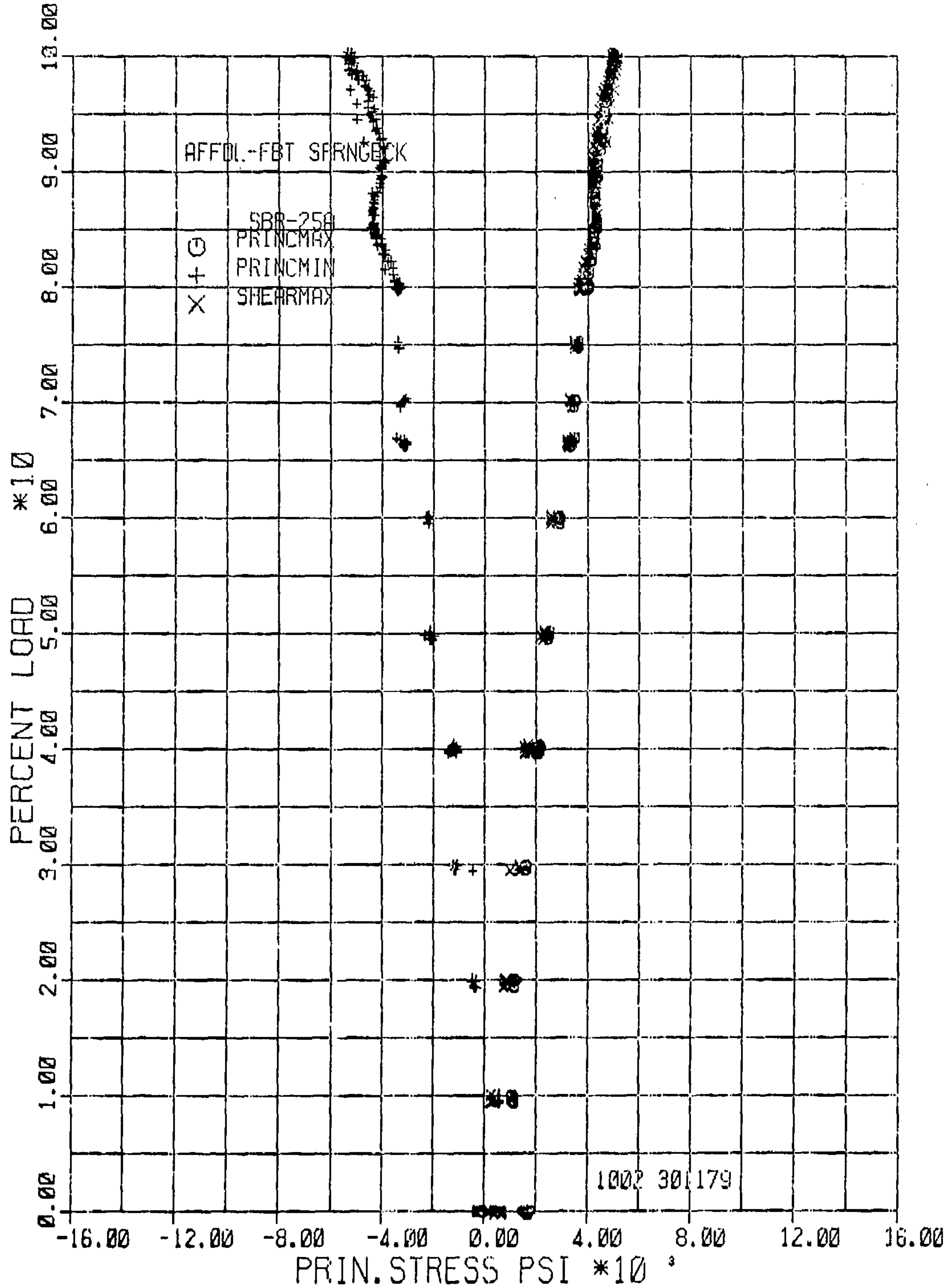


Table C-20. Bulkhead Strain Gage R26 Springback Landing

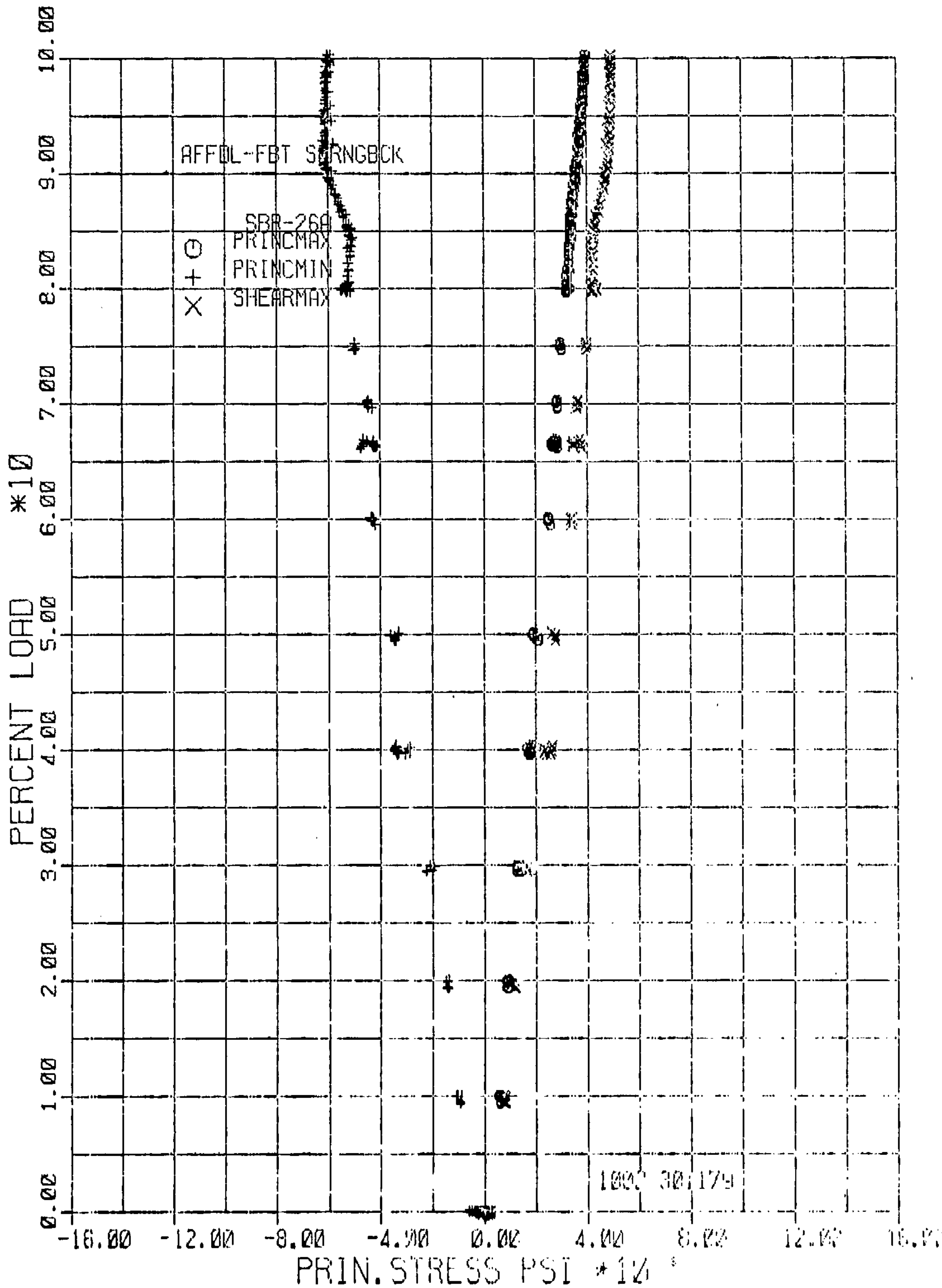


Table C-21. Bulkhead Strain Gage R27 Springback Landing

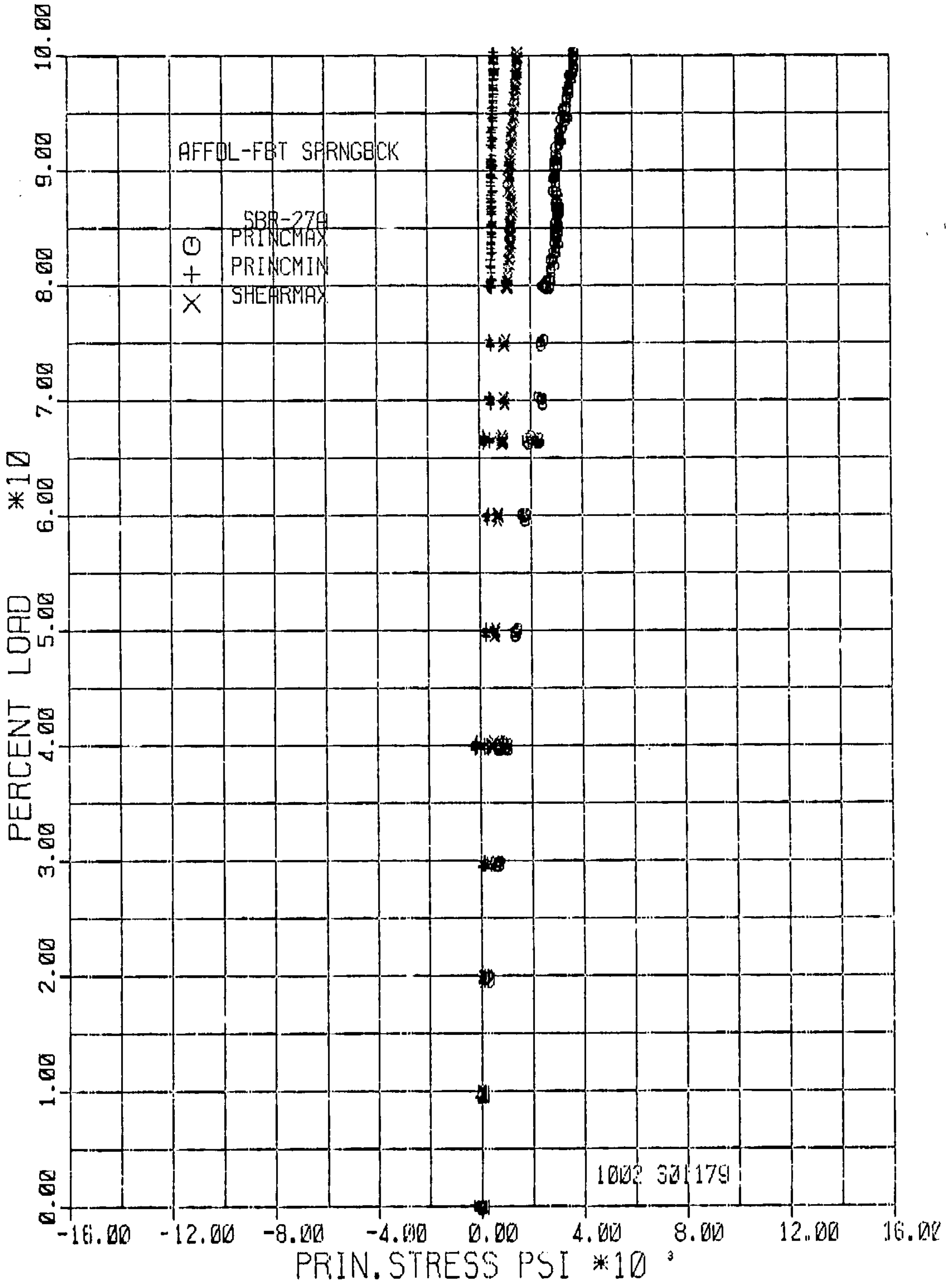


Table C-22. Bulkhead Strain Gage R28 Springback Landing

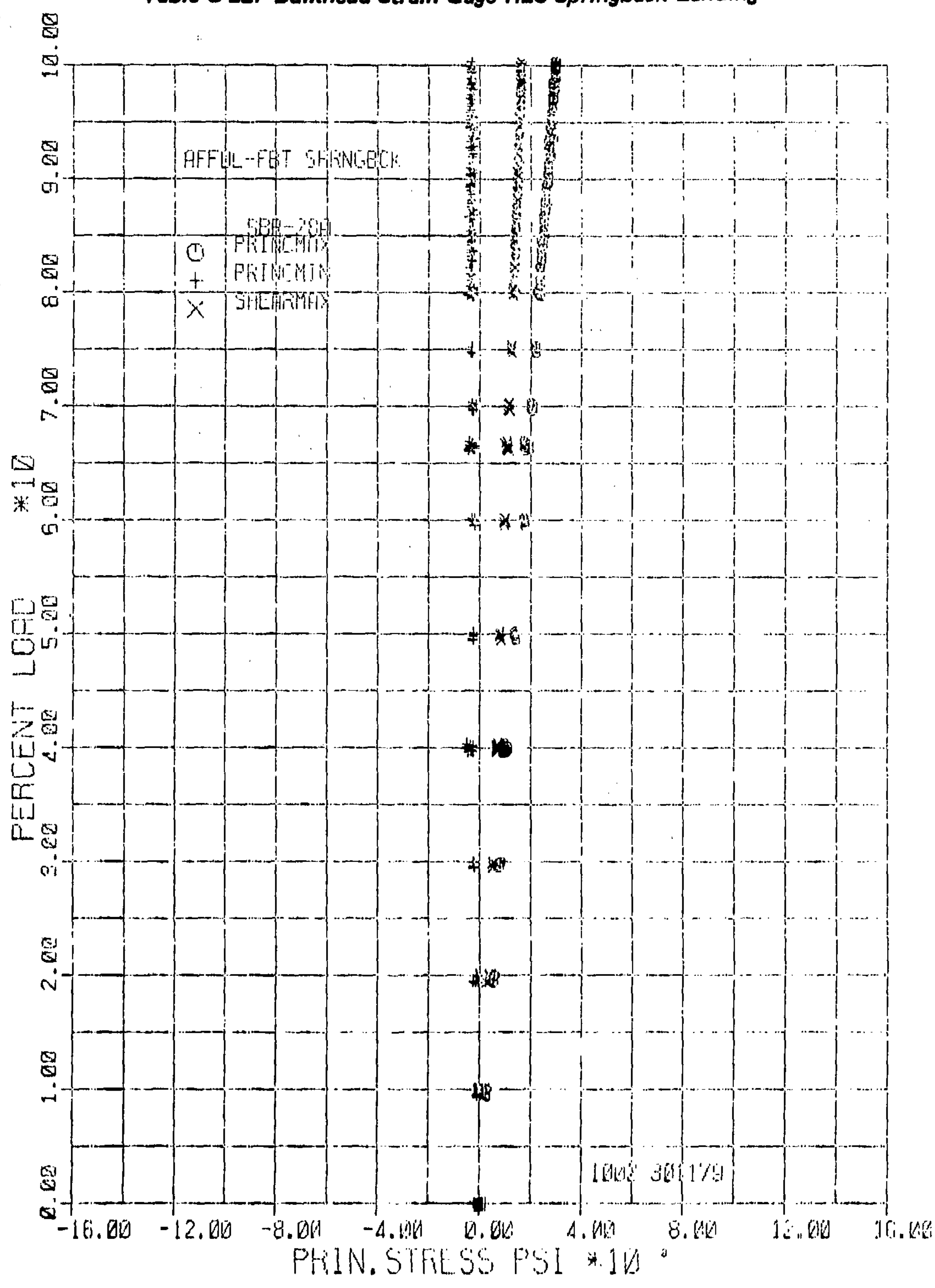


Table C-23. Bulkhead Strain Gage R29 Springback Landing

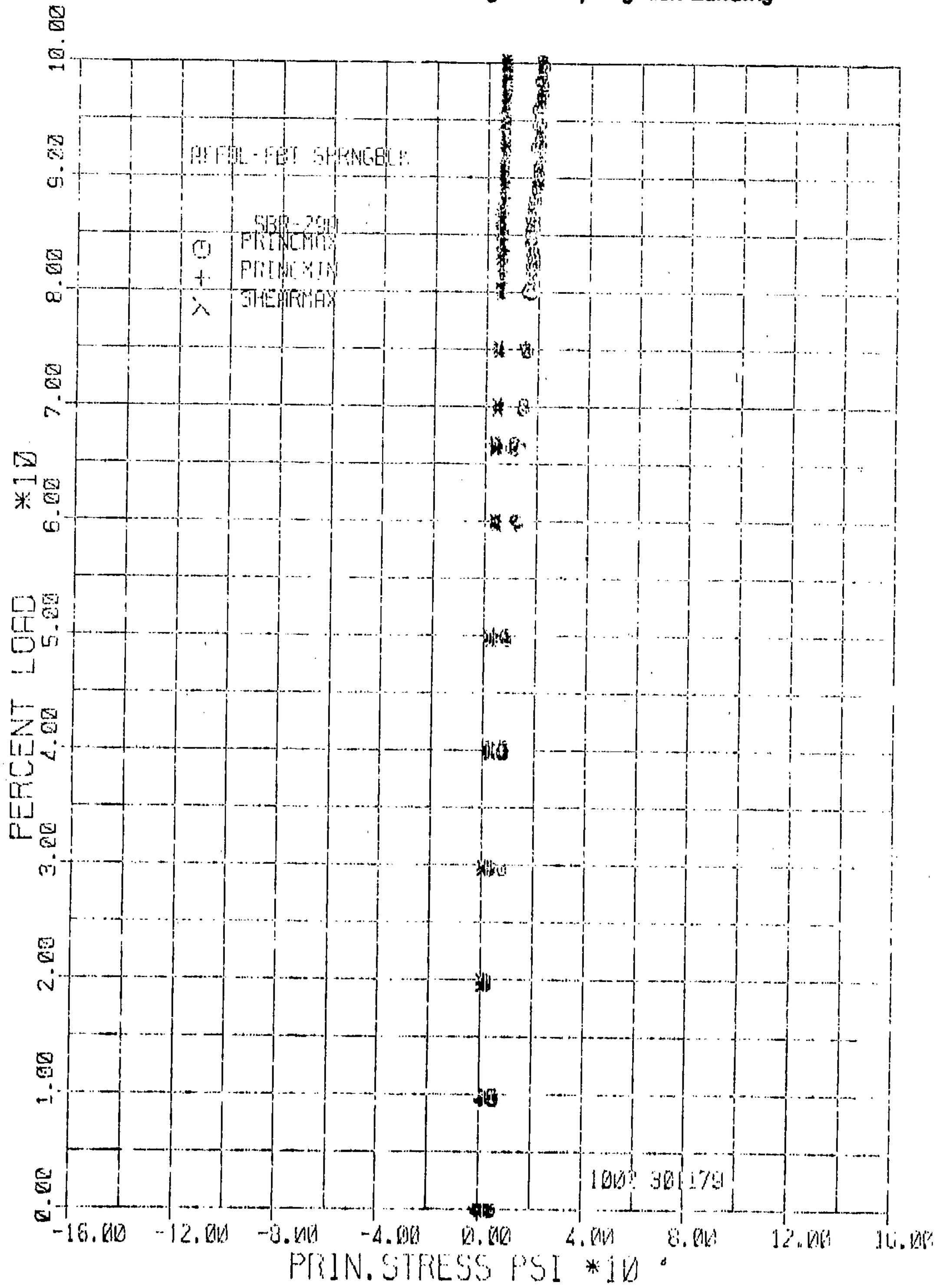


Table C-24. Bulkhead Strain Gage R30 Springback Landing

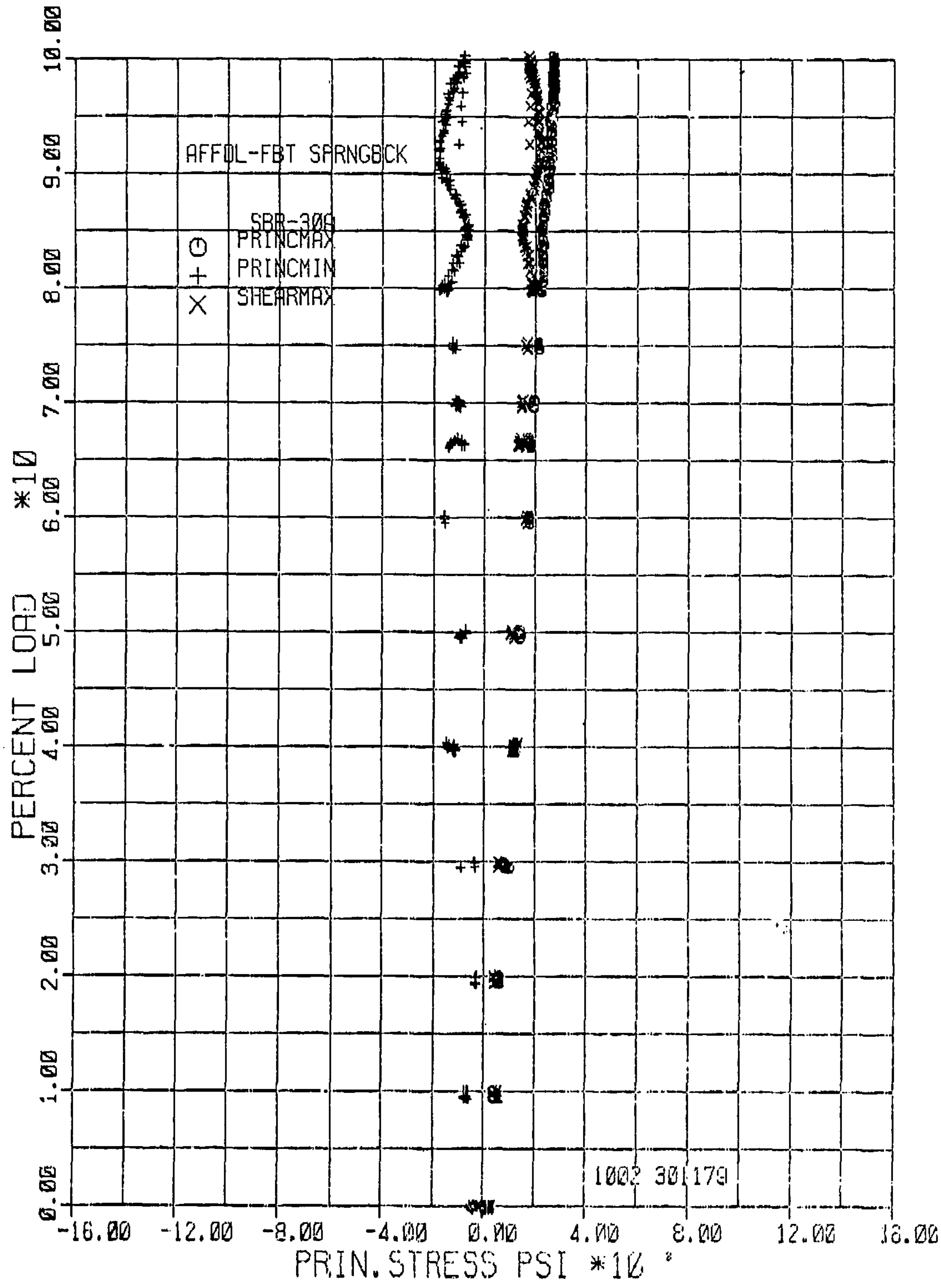


Table C-25. Bulkhead Strain Gage R1 Boeing Side Load Landing

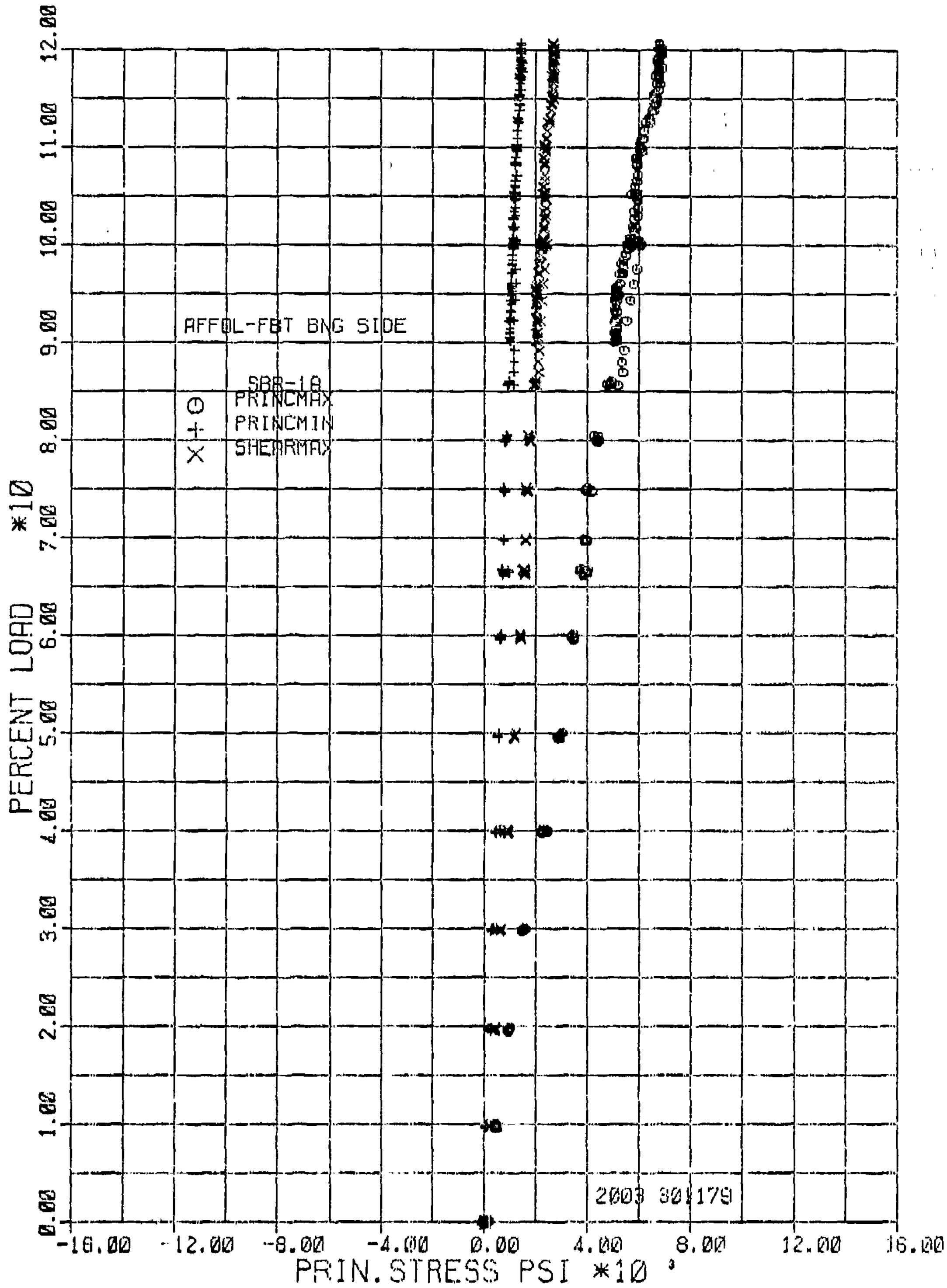


Table C-26. Bulkhead Strain Gage R2 Boeing Side Load Landing

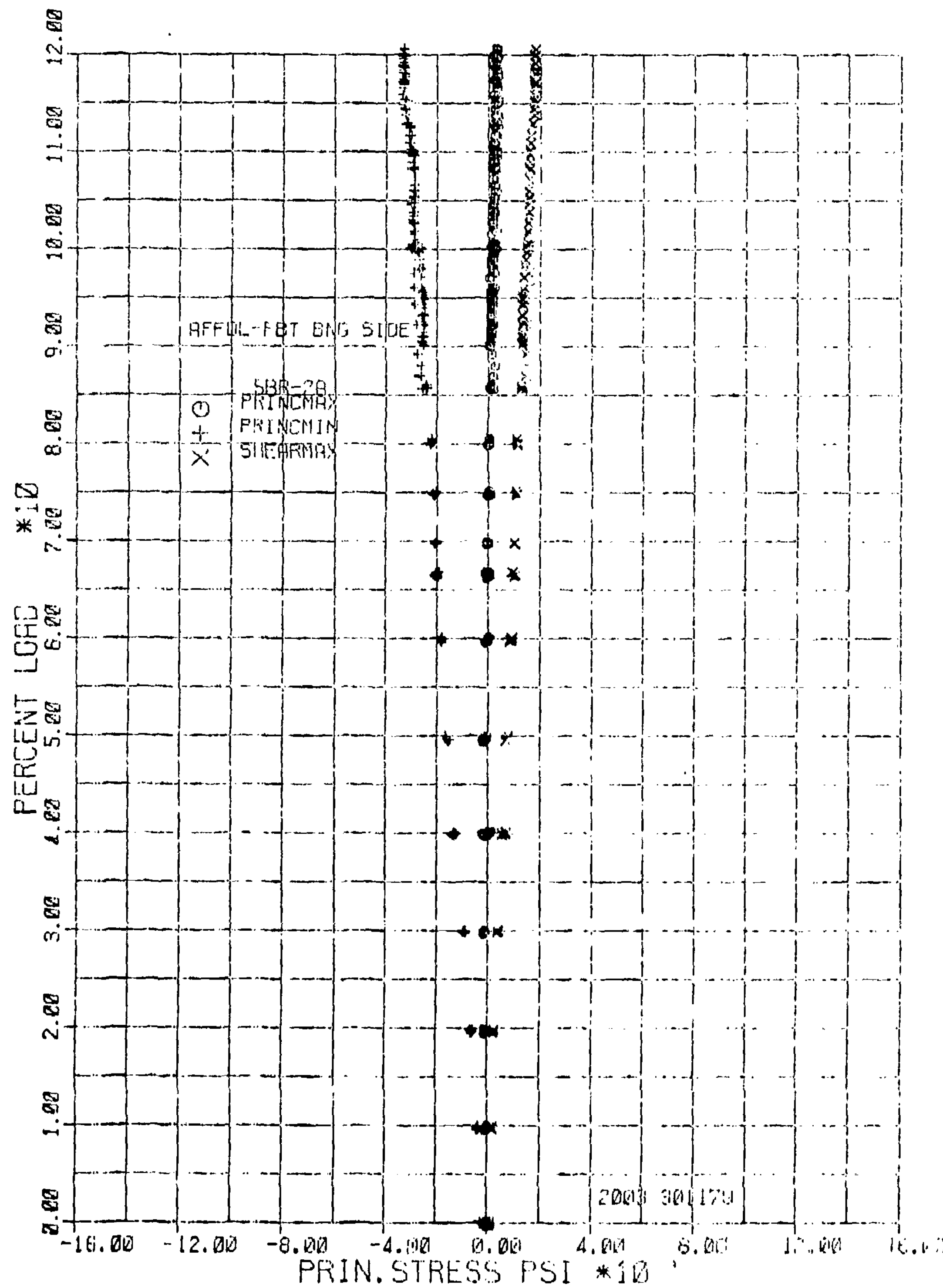


Table C-27. Bulkhead Strain Gage R3 Boeing Side Load Landing

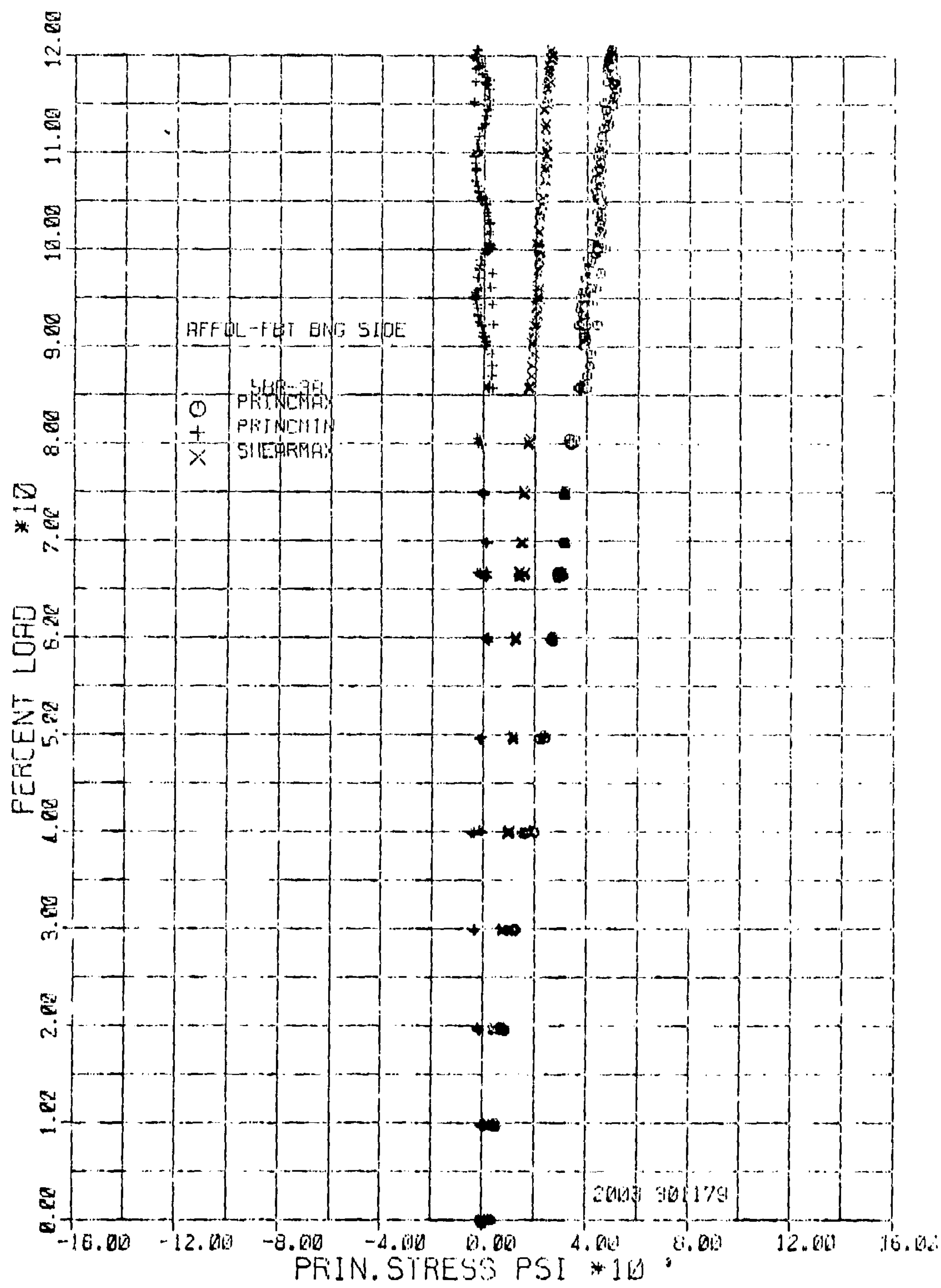


Table C-28. Bulkhead Strain Gage R4 Boeing Side Load Landing

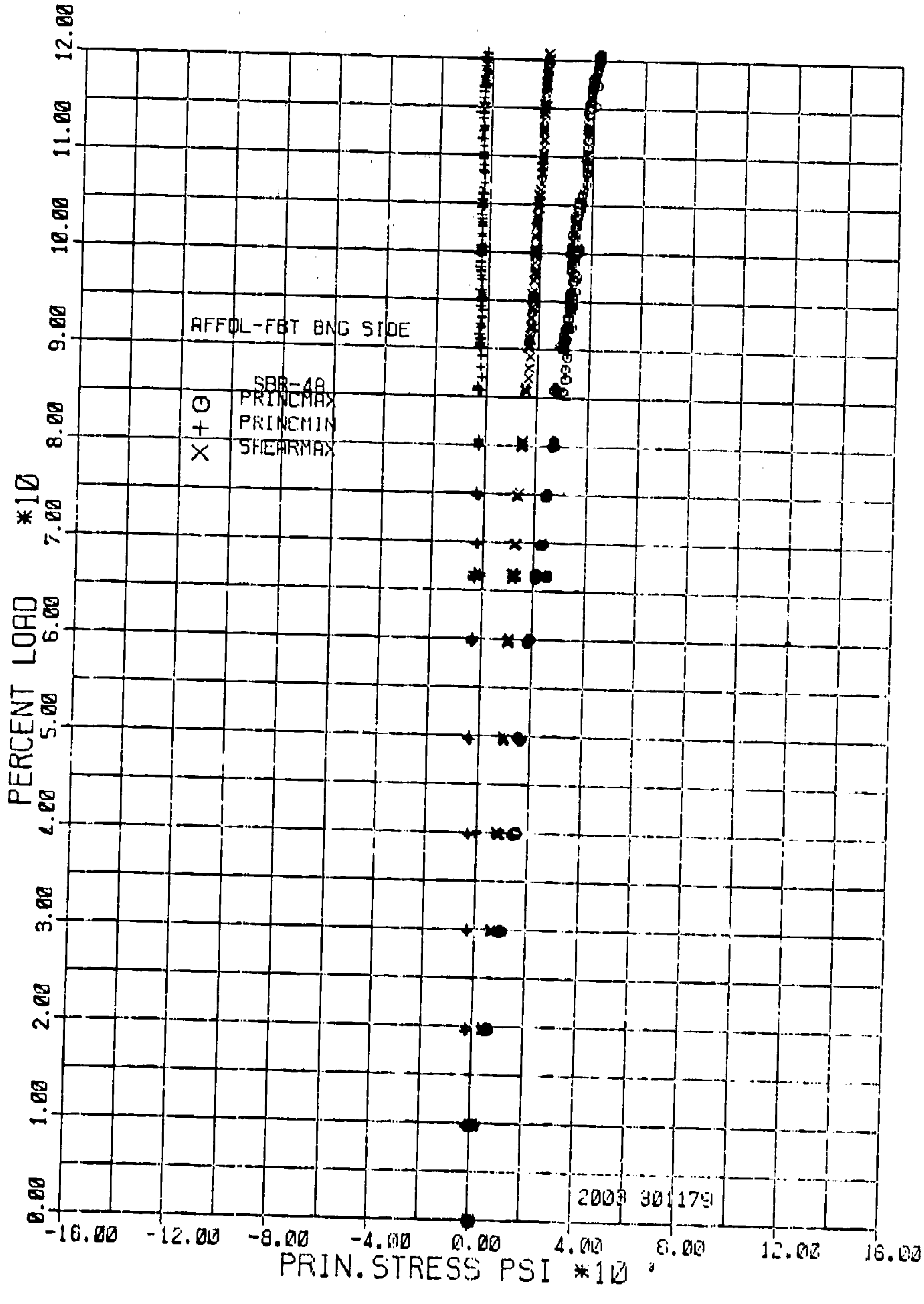


Table C-29. Bulkhead Strain Gage R5 Boeing Side Load Landing

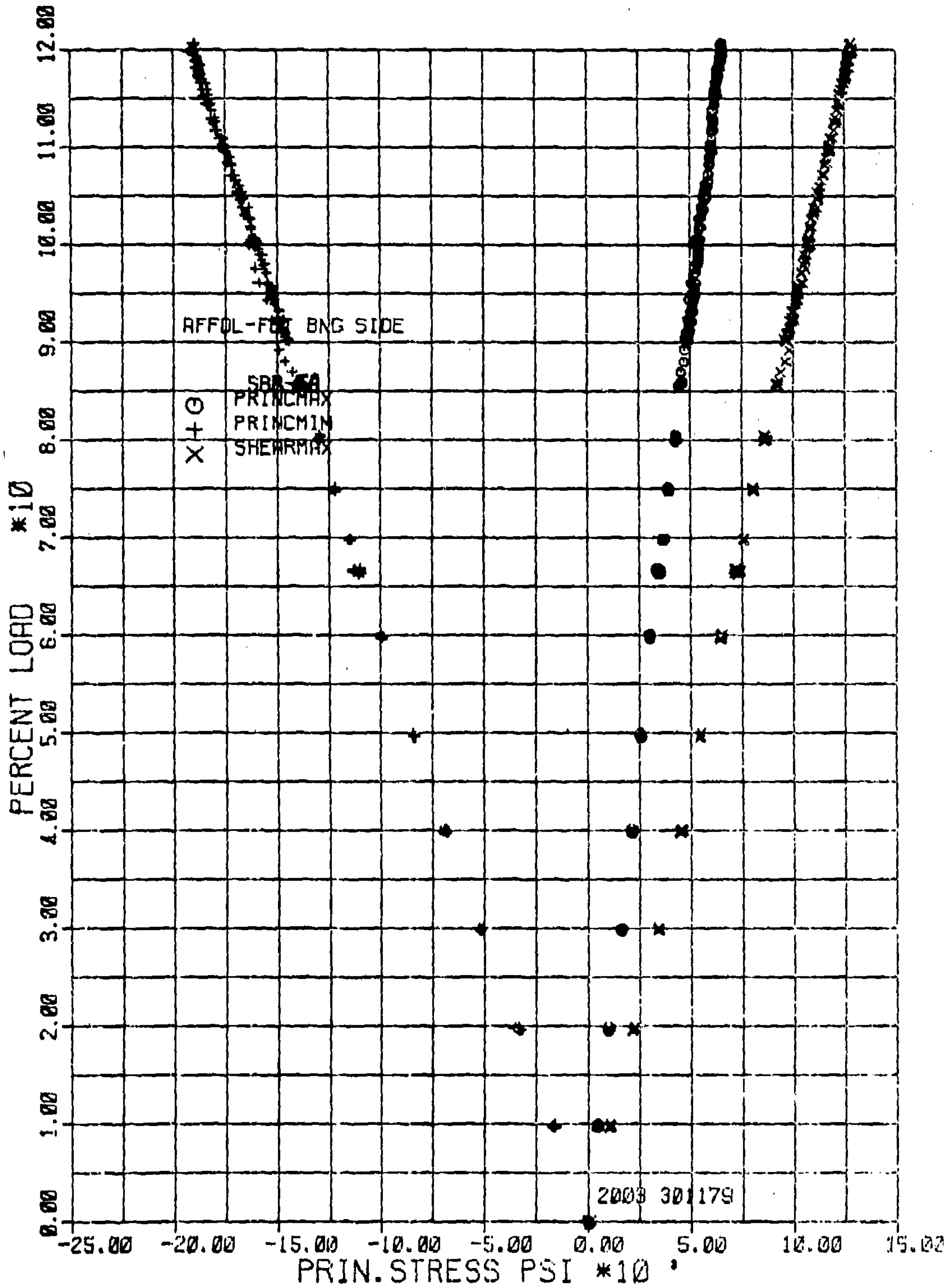


Table C-30. Bulkhead Strain Gage R7 Boeing Side Load Landing

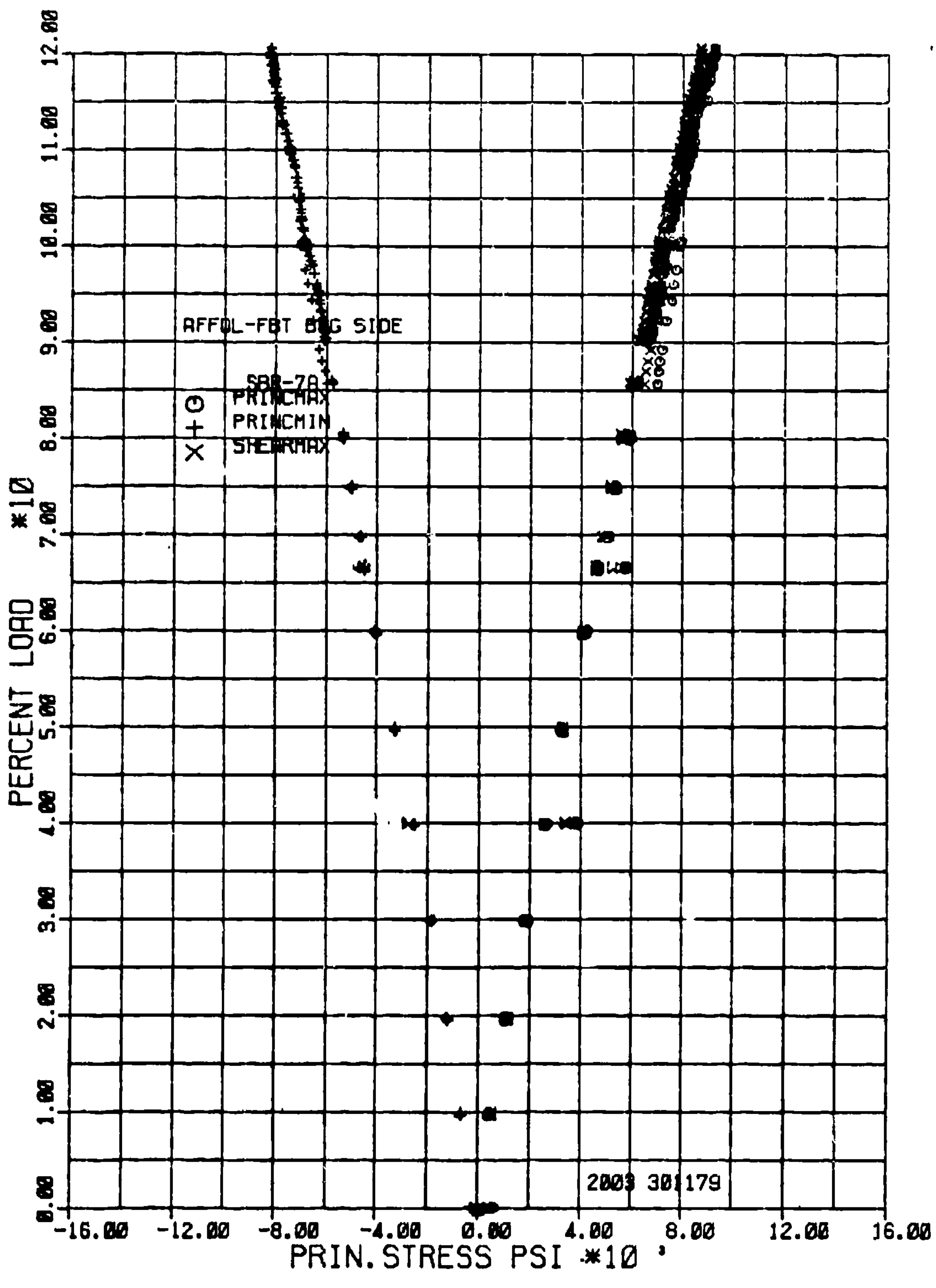


Table C-31. Bulkhead Strain Gage R8 Boeing Side Load Landing

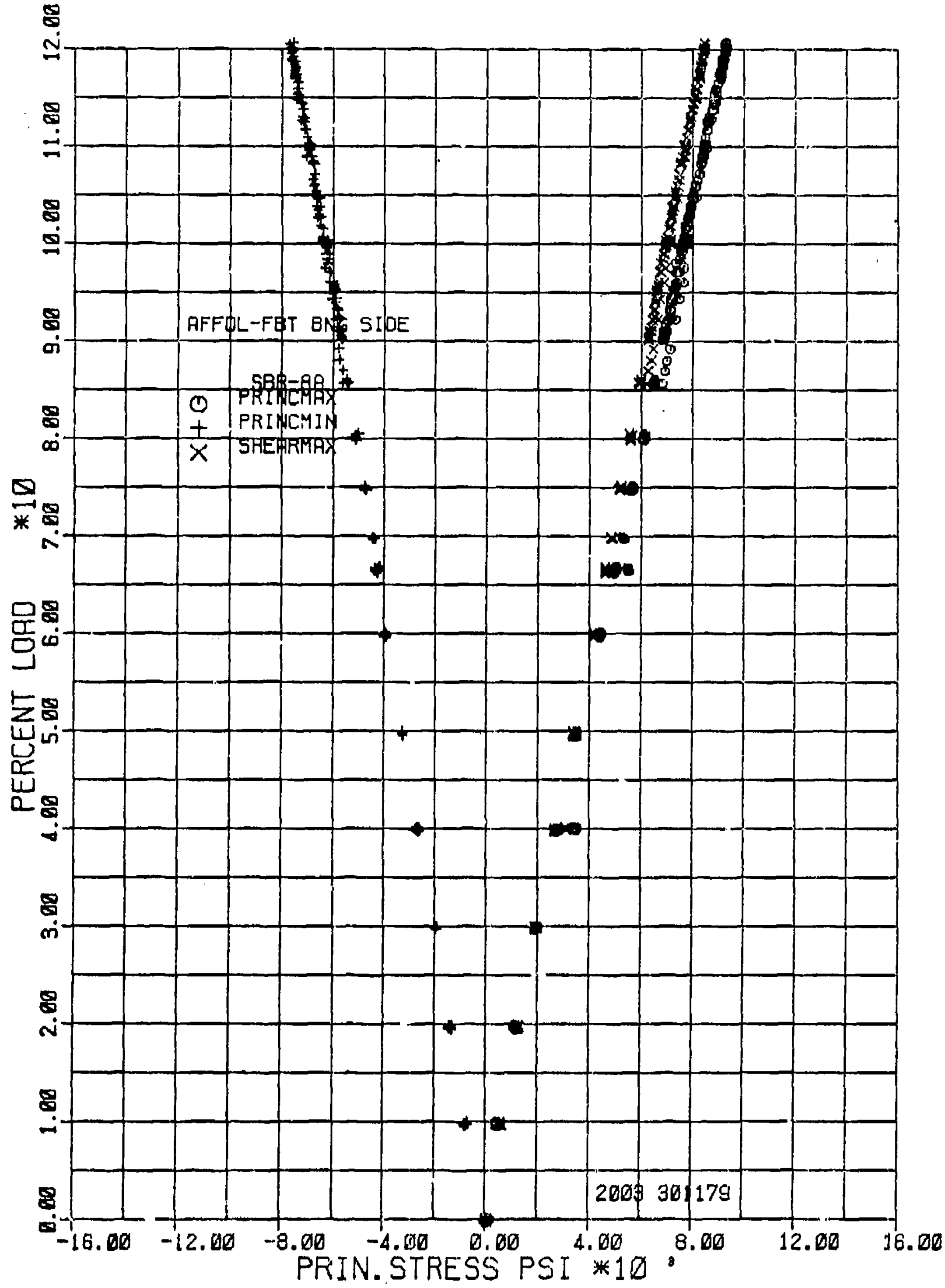


Table C-32. Bulkhead Strain Gage R9 Boeing Side Load Landing

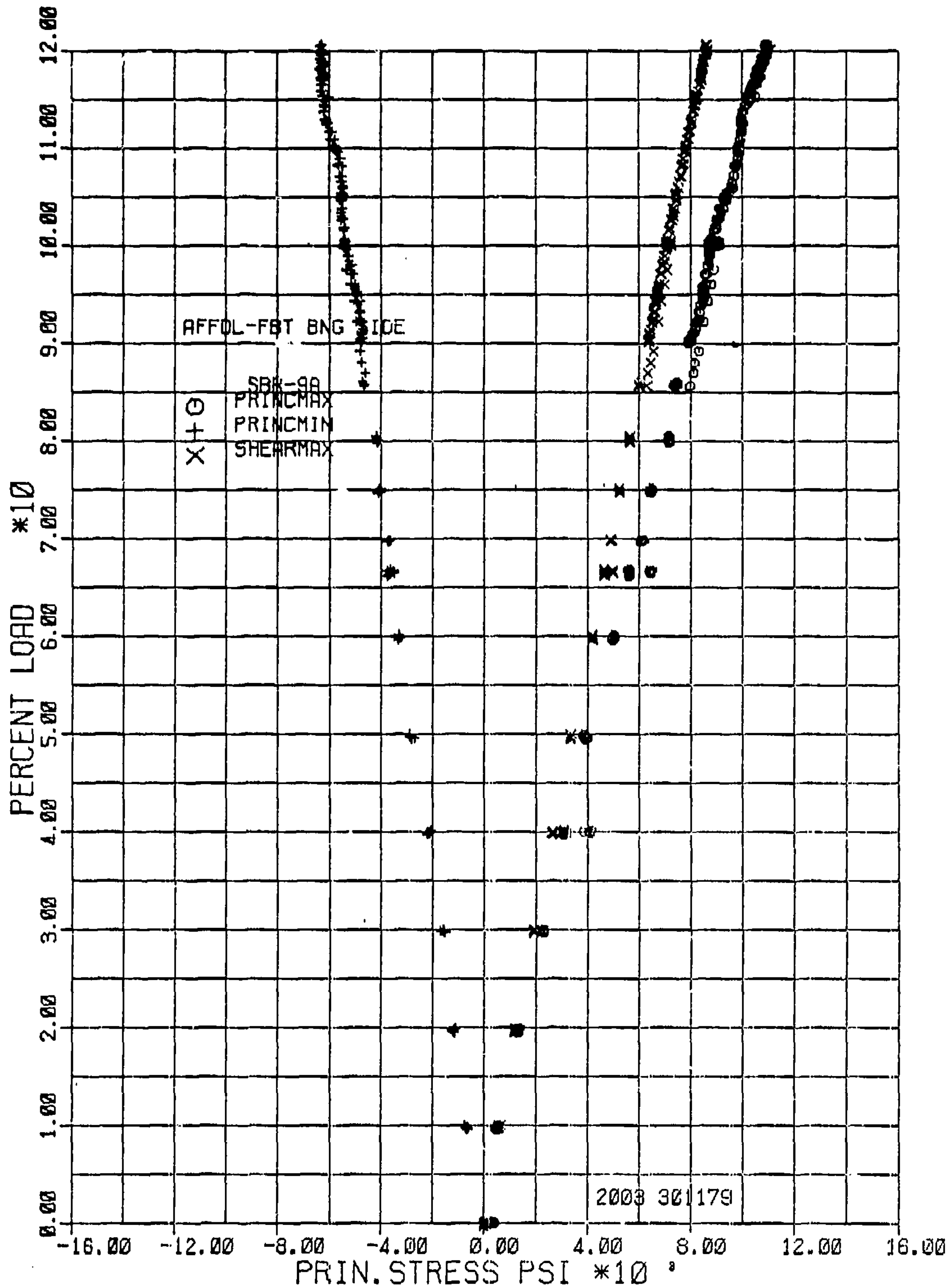


Table C-33. Bulkhead Strain Gage R10 Boeing Side Load Landing

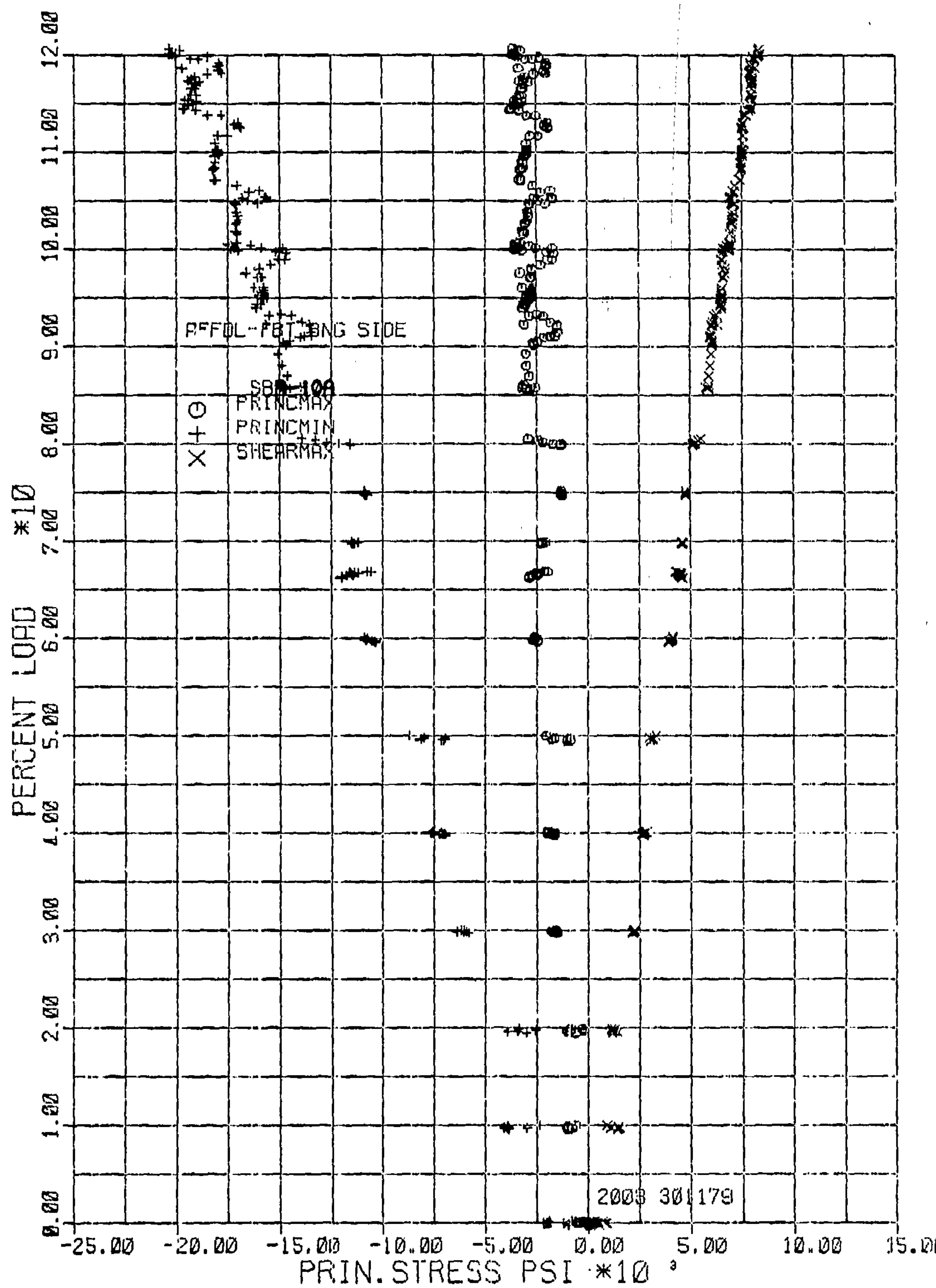


Table C-34. Bulkhead Strain Gage R11 Boeing Side Load Landing

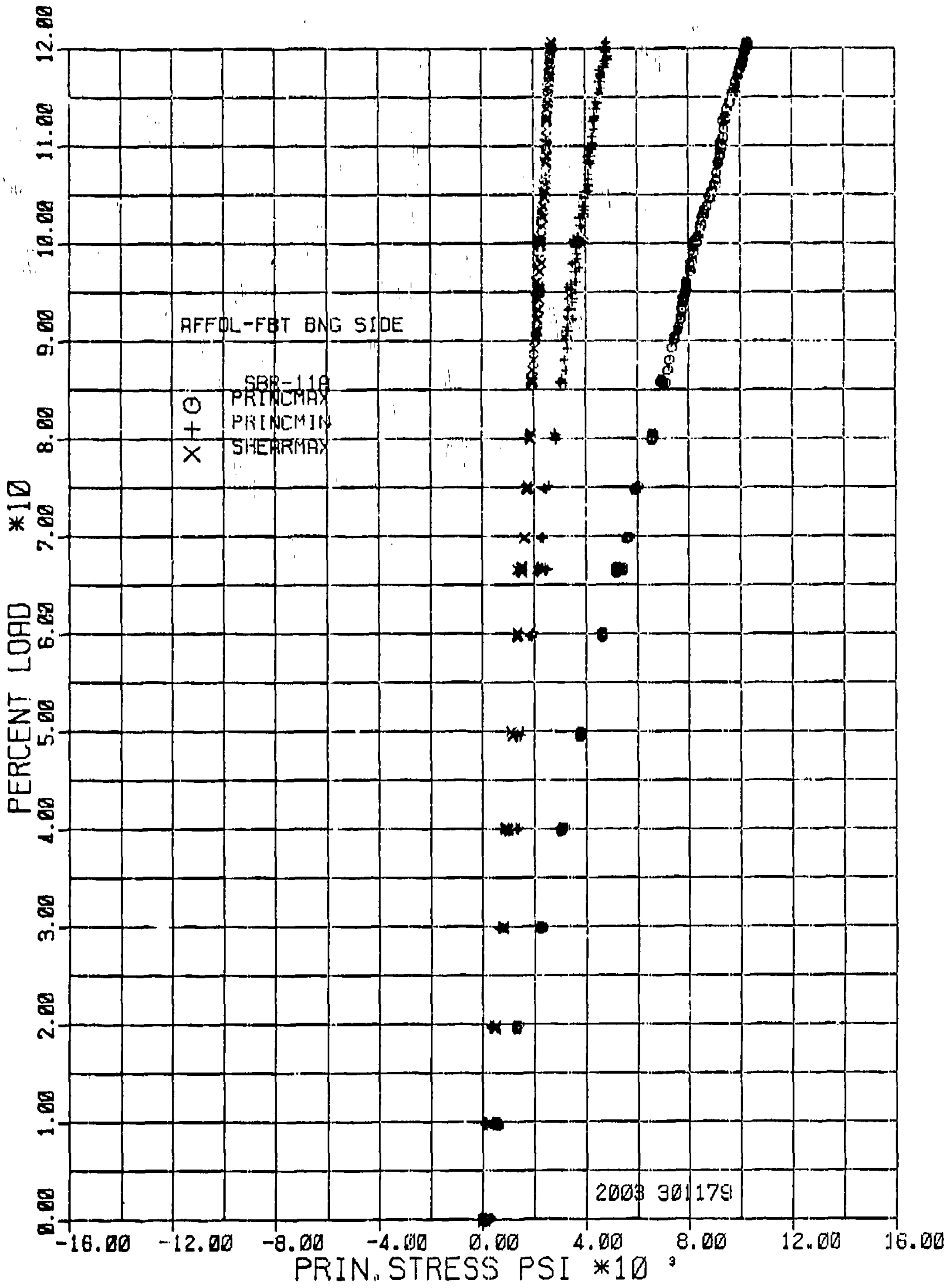


Table C-35. Bulkhead Strain Gage B12 Boeing Side Load Landing

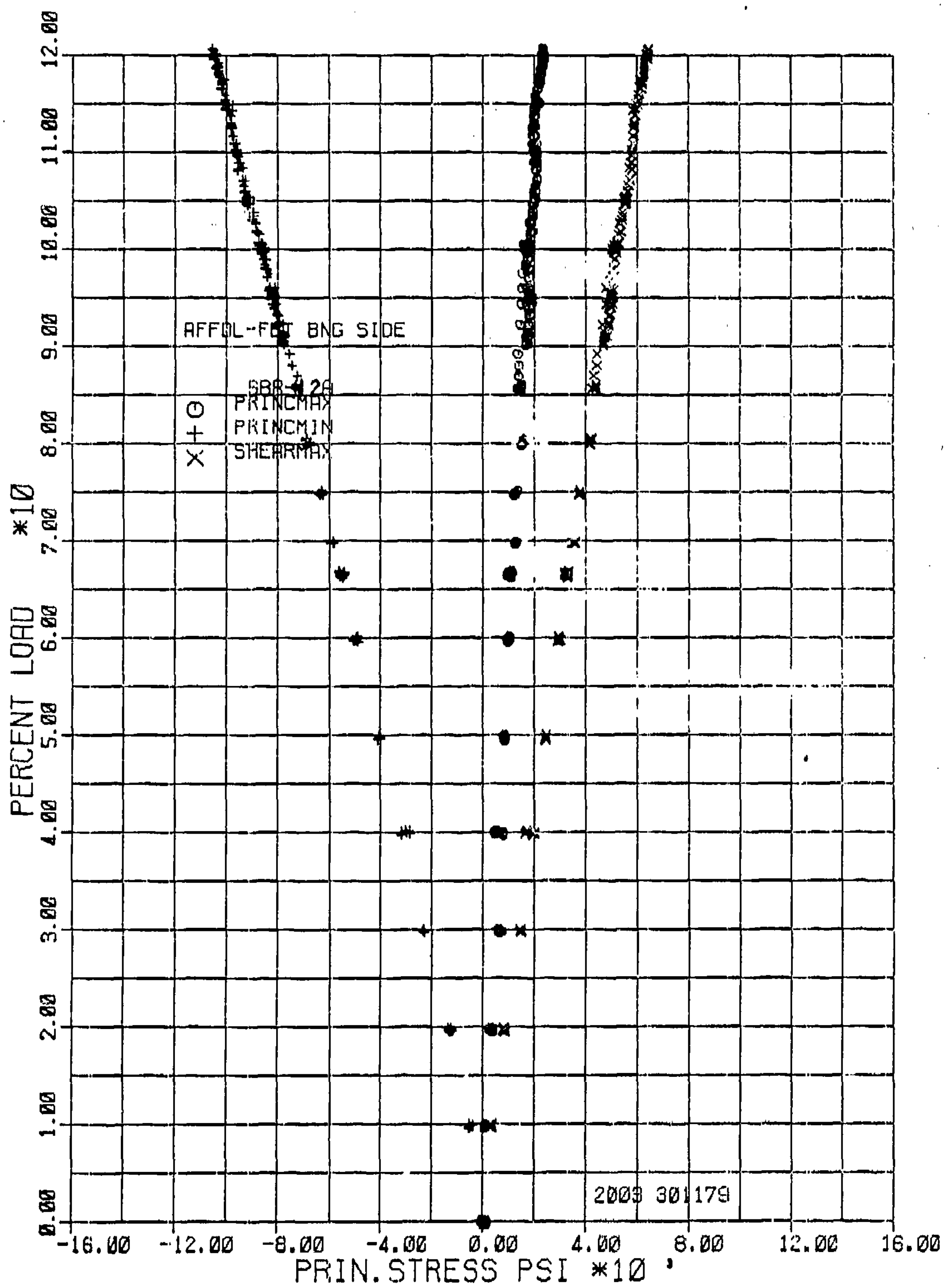


Table C-36. Bulkhead Strain Gage R13 Boeing Side Load Landing

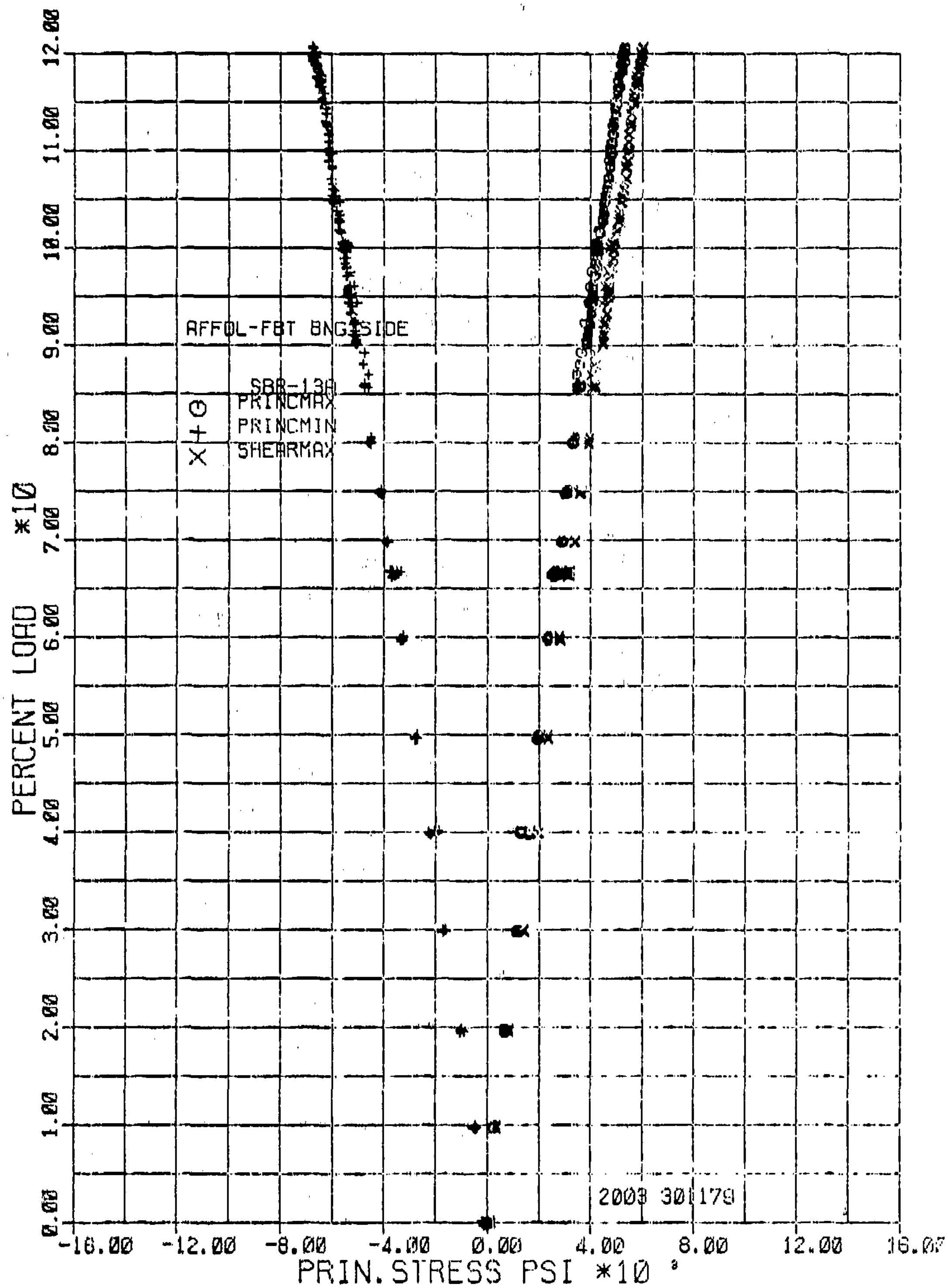


Table C-37. Bulkhead Strain Gage R15 Boeing Side Load Loading

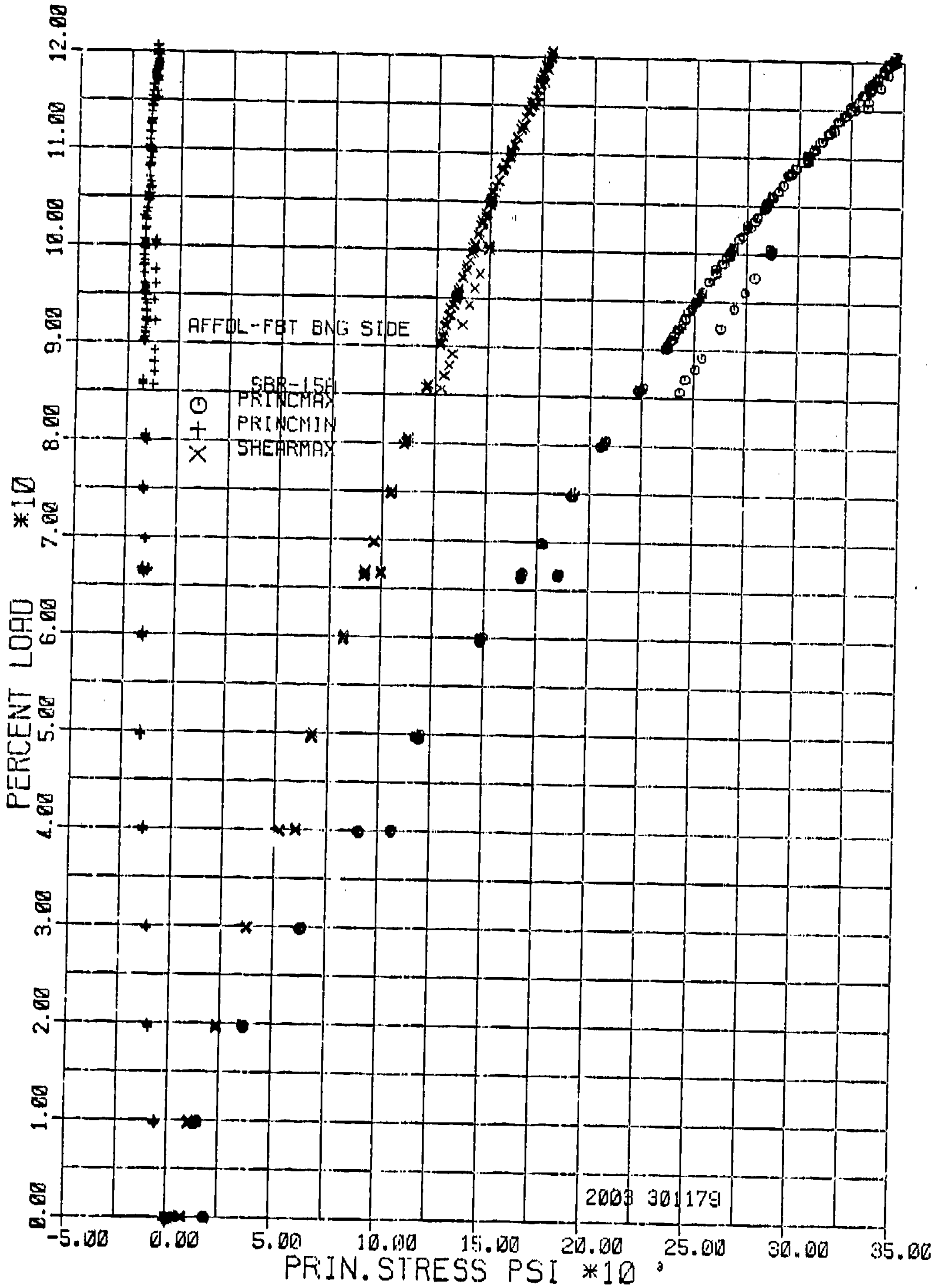


Table C-38. Bulkhead Strain Gage R16 Boeing Side Load Landing

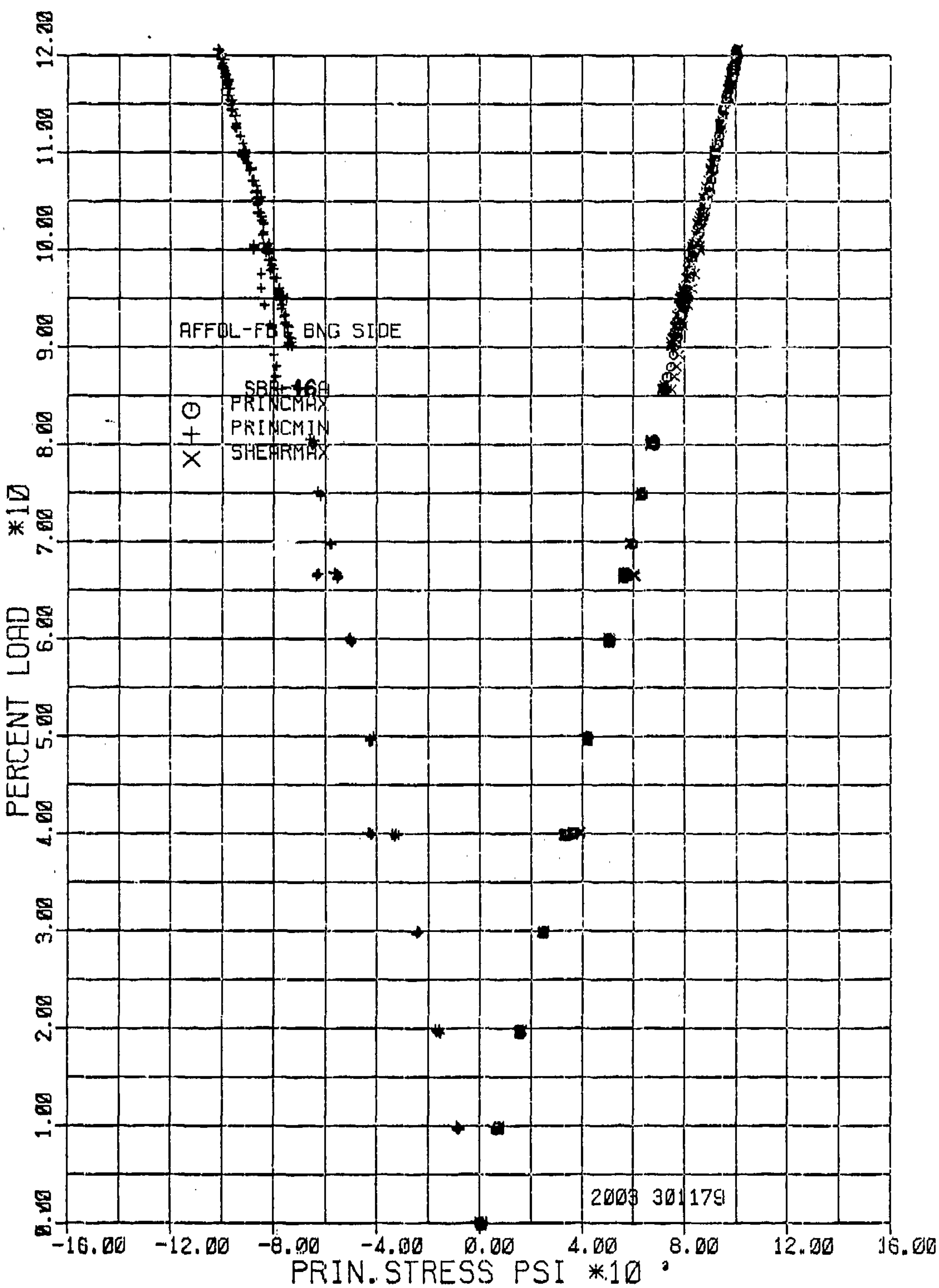


Table C-39. Bulkhead Strain Gage R17 Boeing Side Load Landing

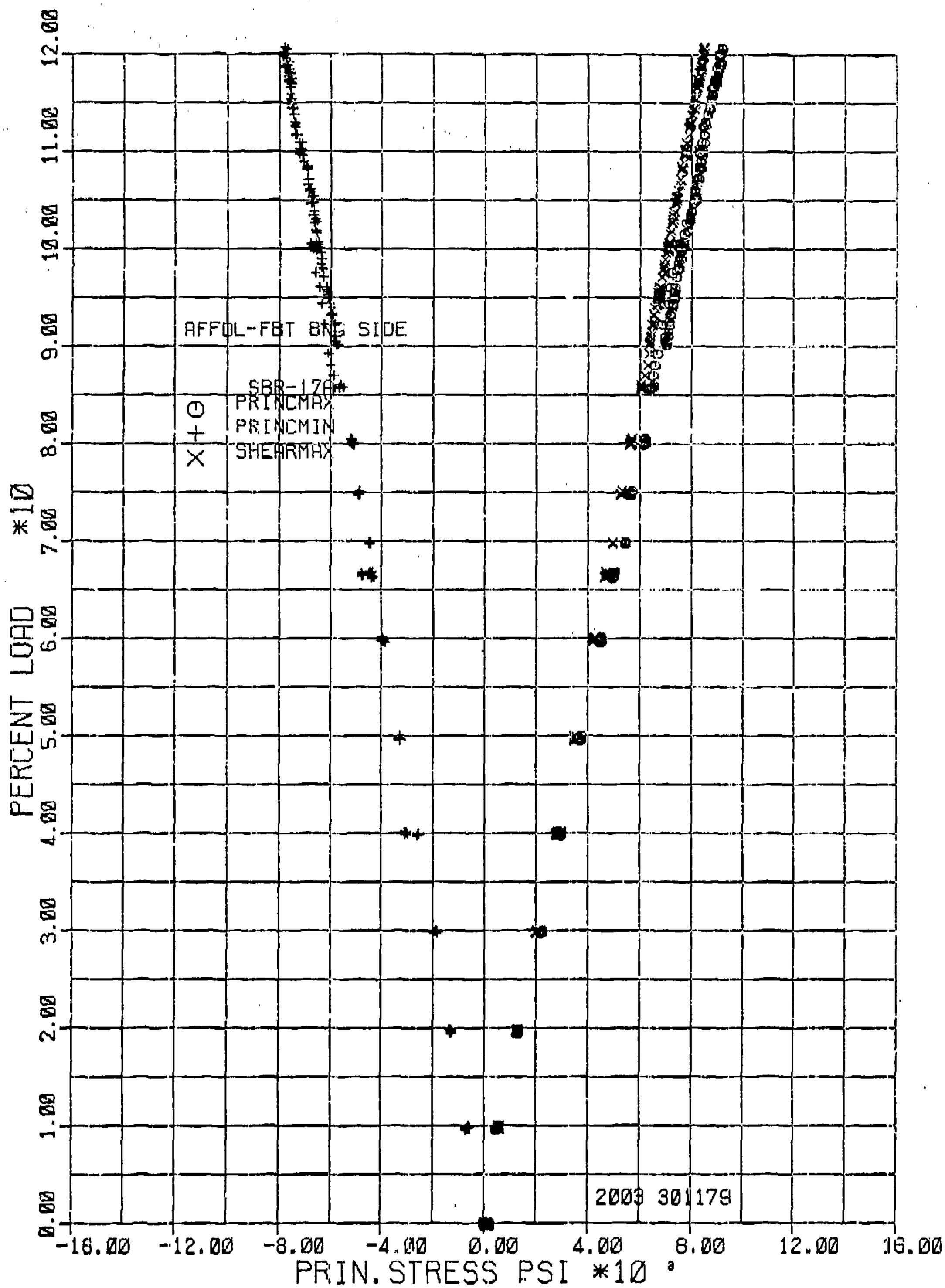


Table C-4C. Bulkhead Strain Gage R18 Boeing Side Load Landing

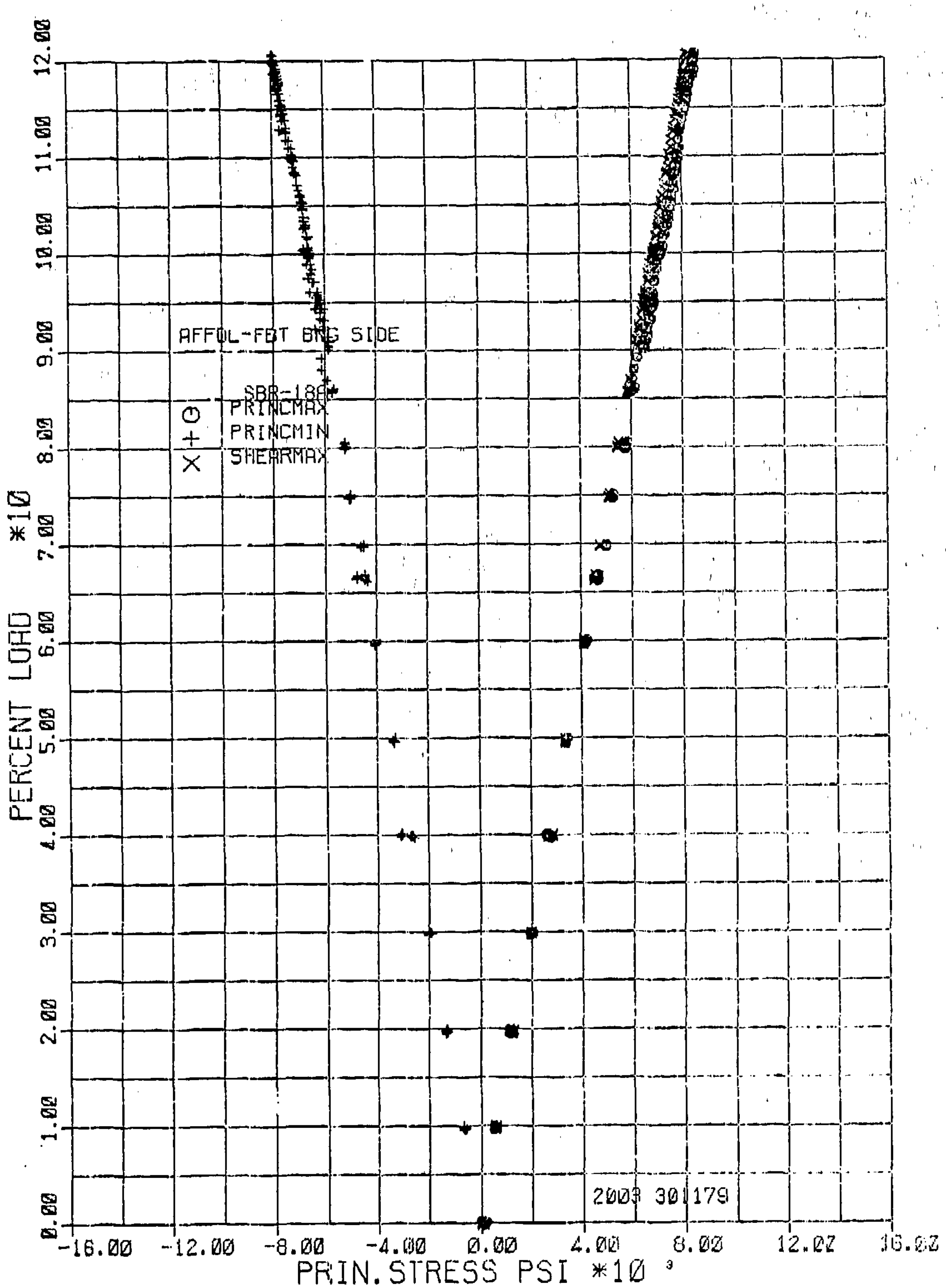


Table C-41. Bulkhead Strain Gage R20 Boeing Side Load Landing

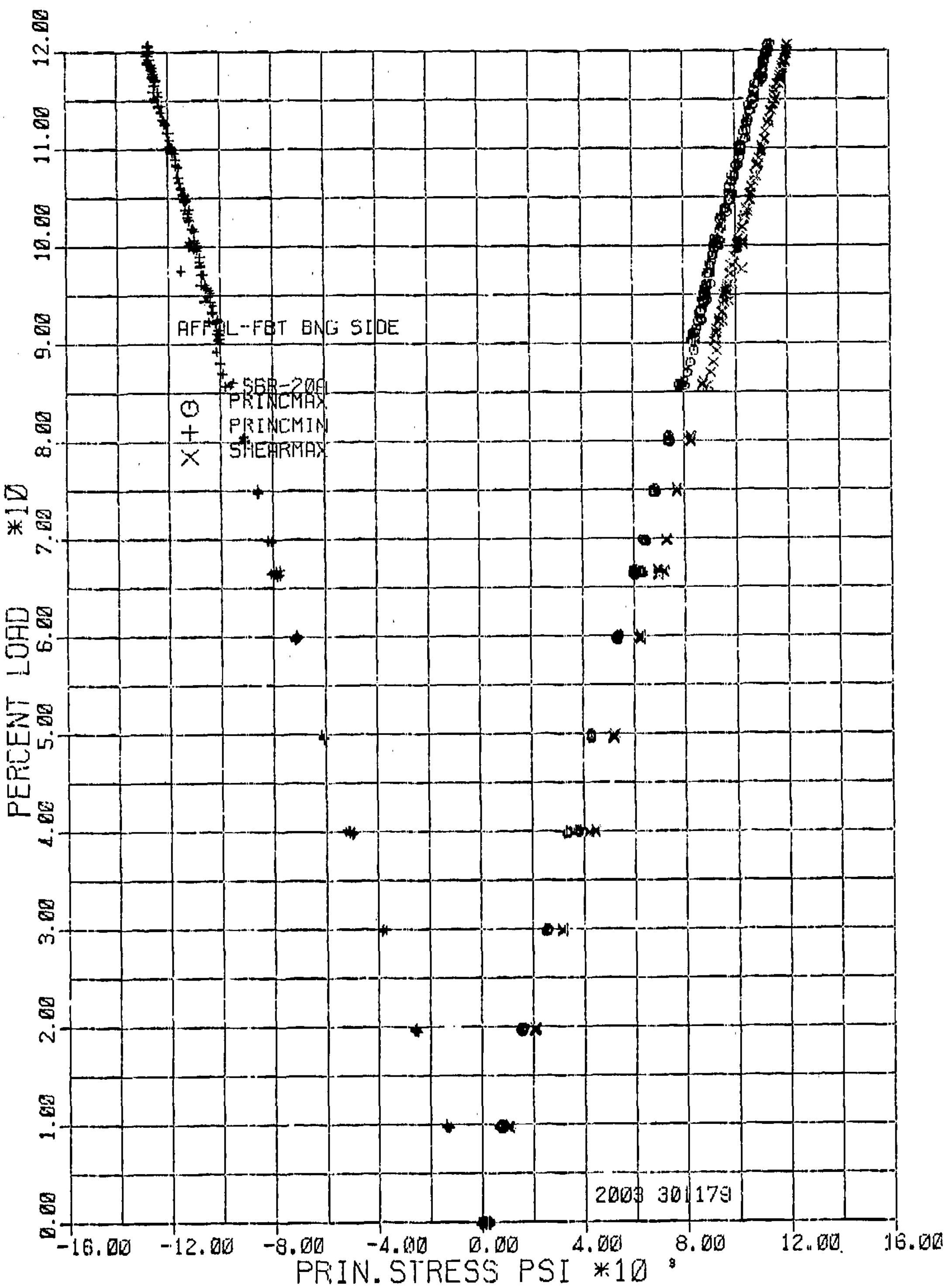


Table C-42. Bulkhead Strain Gage R21 Boeing Side Load Landing

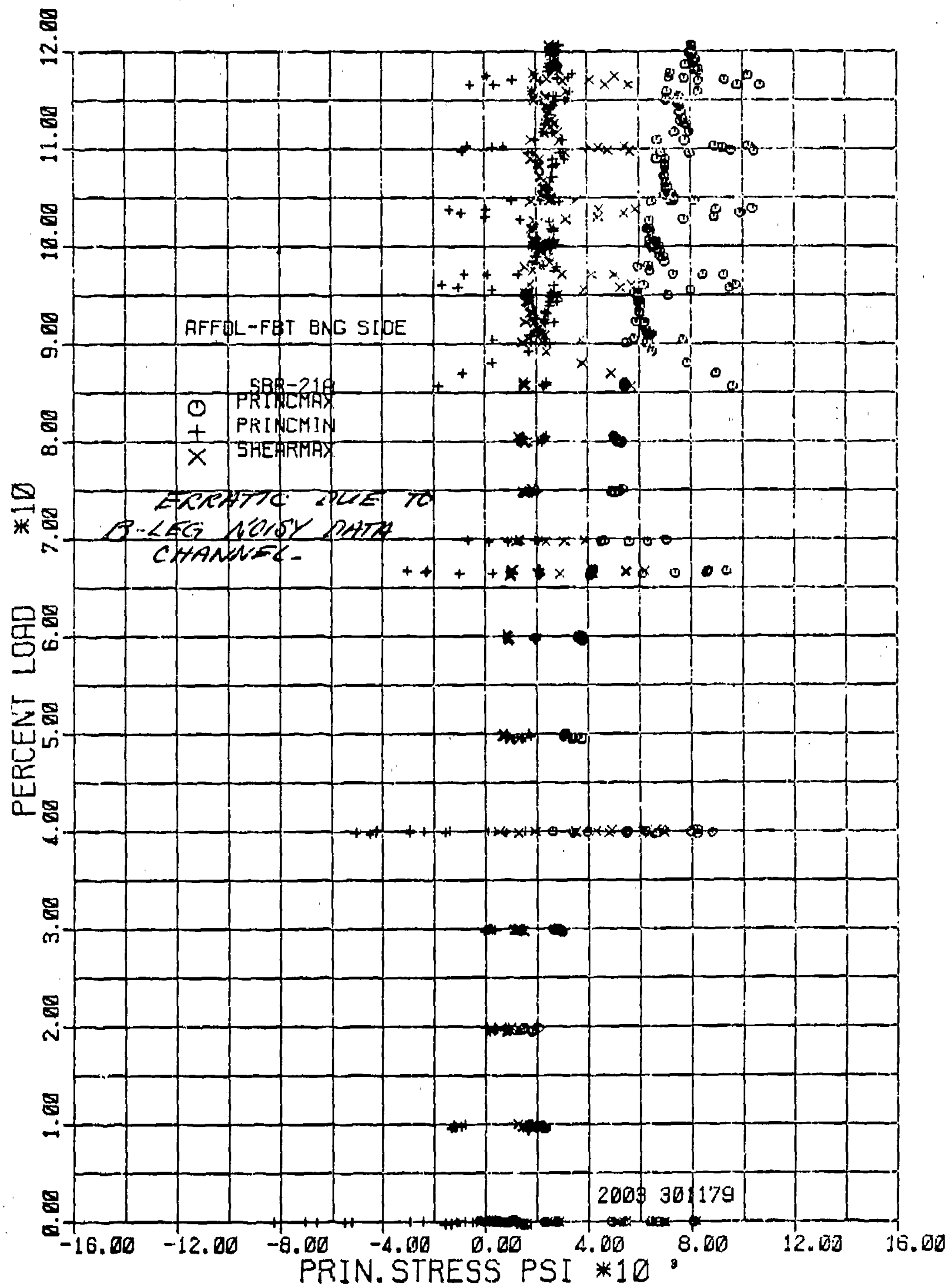


Table C-43. Bulkhead Strain Gage R25 Boeing Side Load Landing

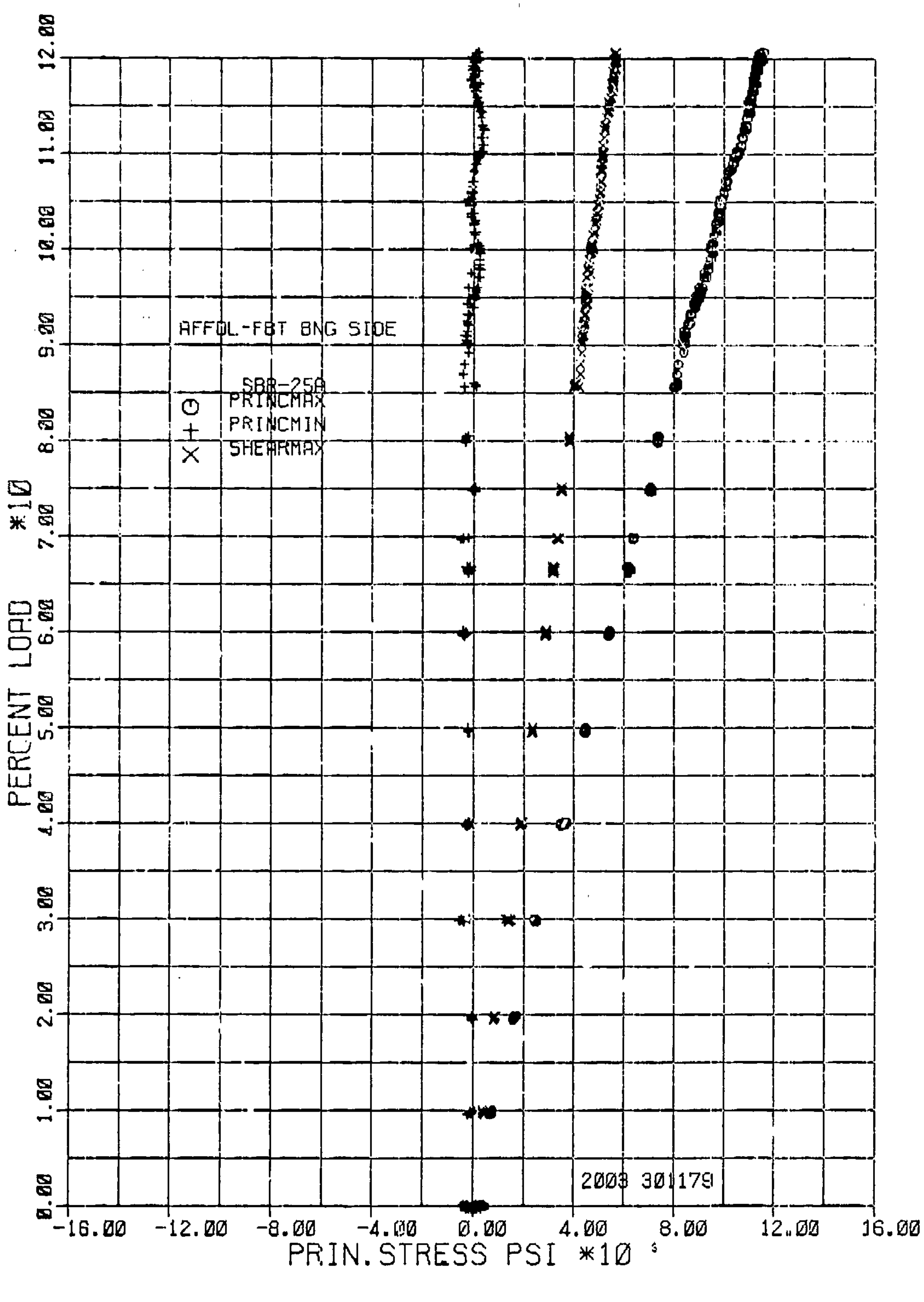


Table C-44. Bulkhead Strain Gage R26 Boeing Side Load Landing

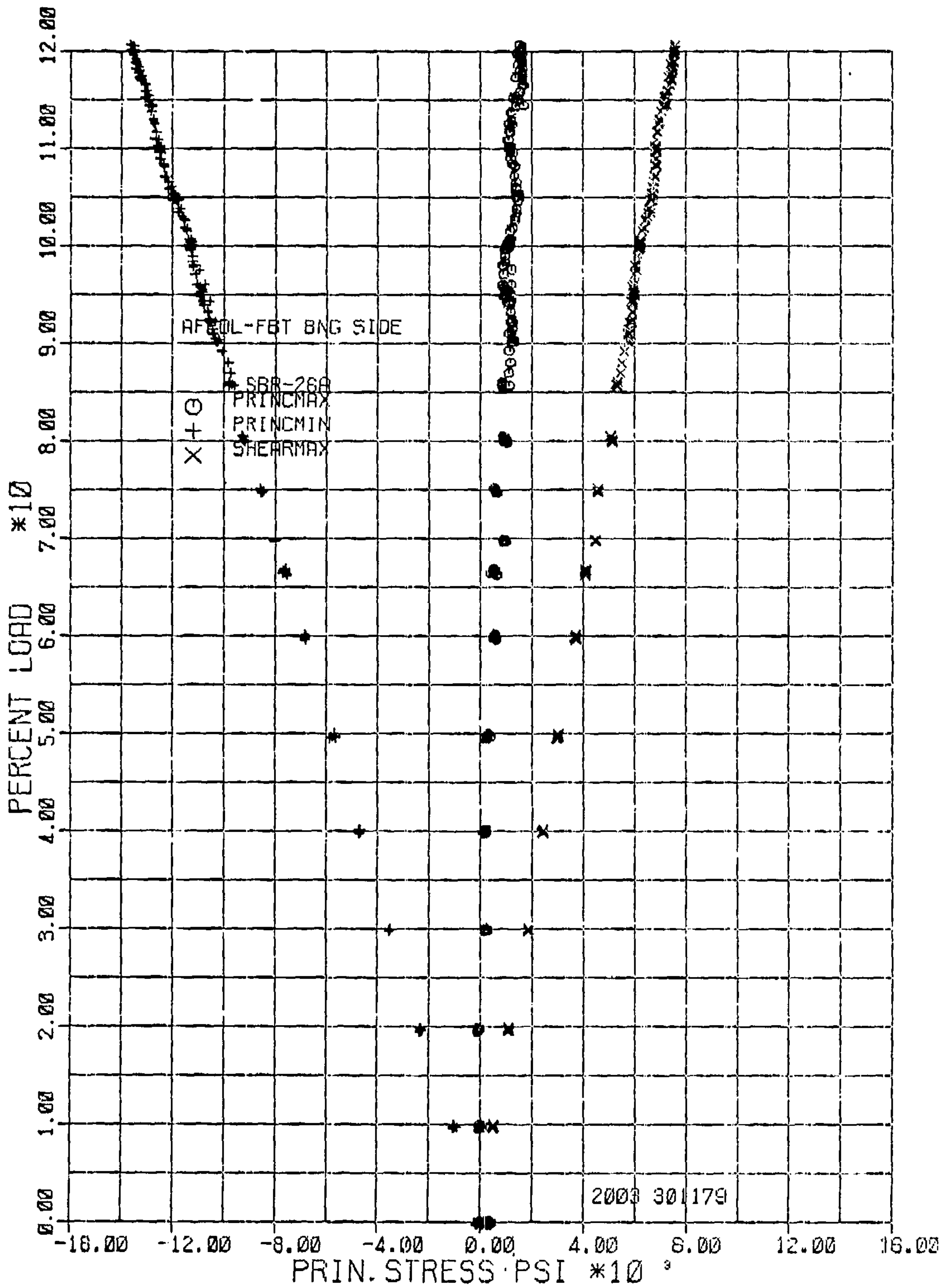


Table C-45. Bulkhead Strain Gage R27 Boeing Side Load Landing

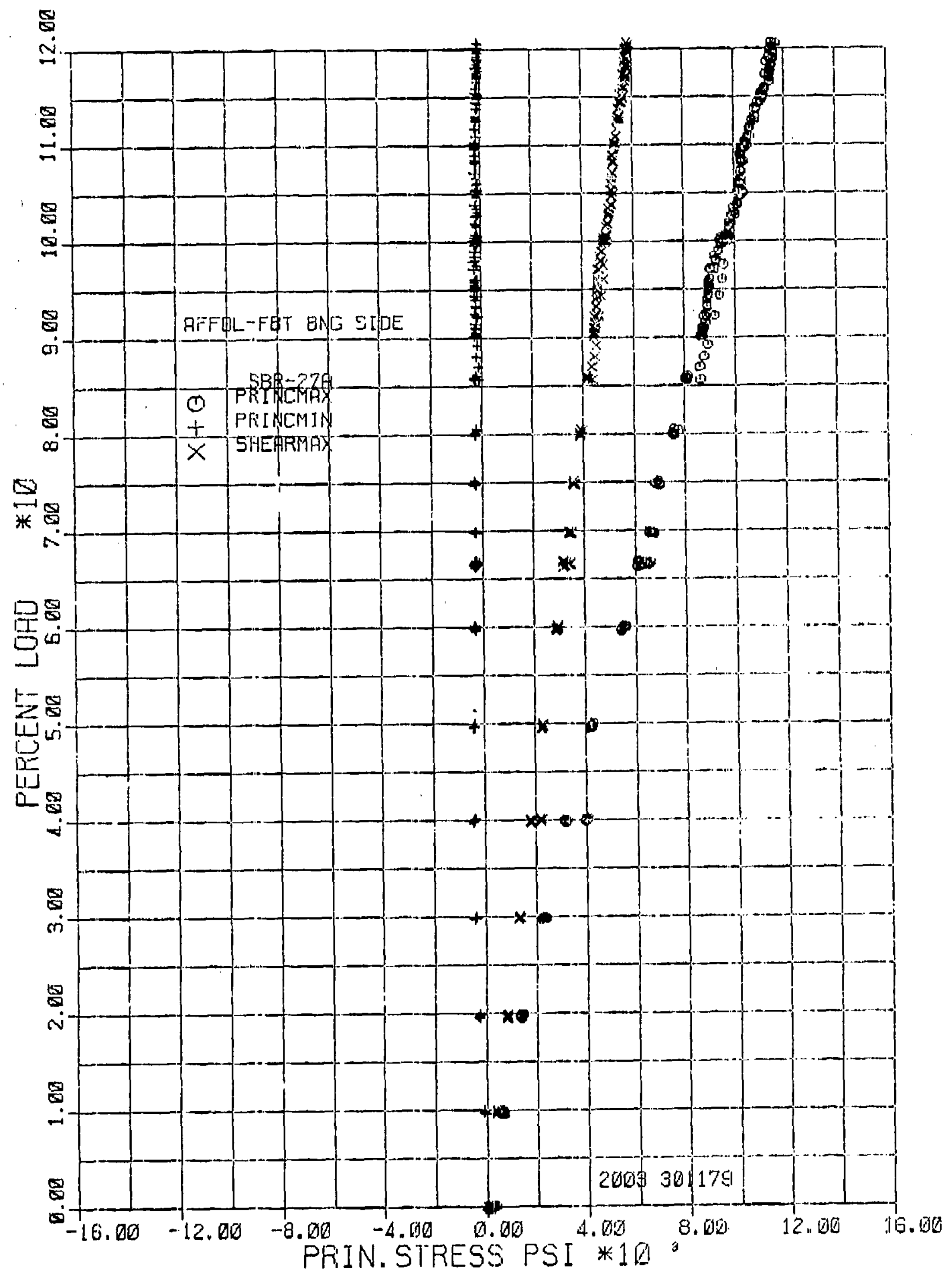


Table C-46. Bulkhead Strain Gage R28 Boeing Side Load Landing

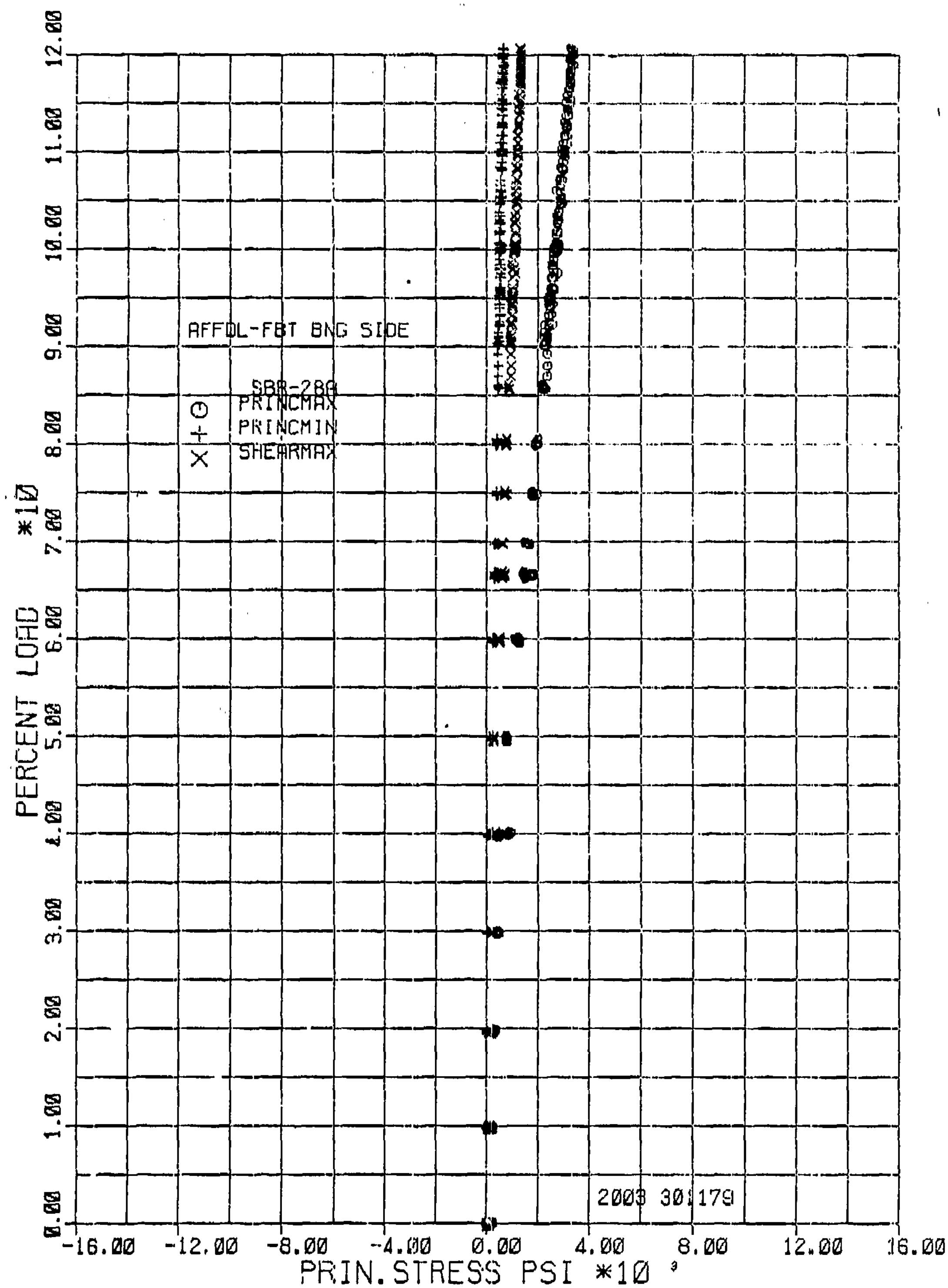


Table C-47. Bulkhead Strain Gage R29 Boeing Side Load Landing

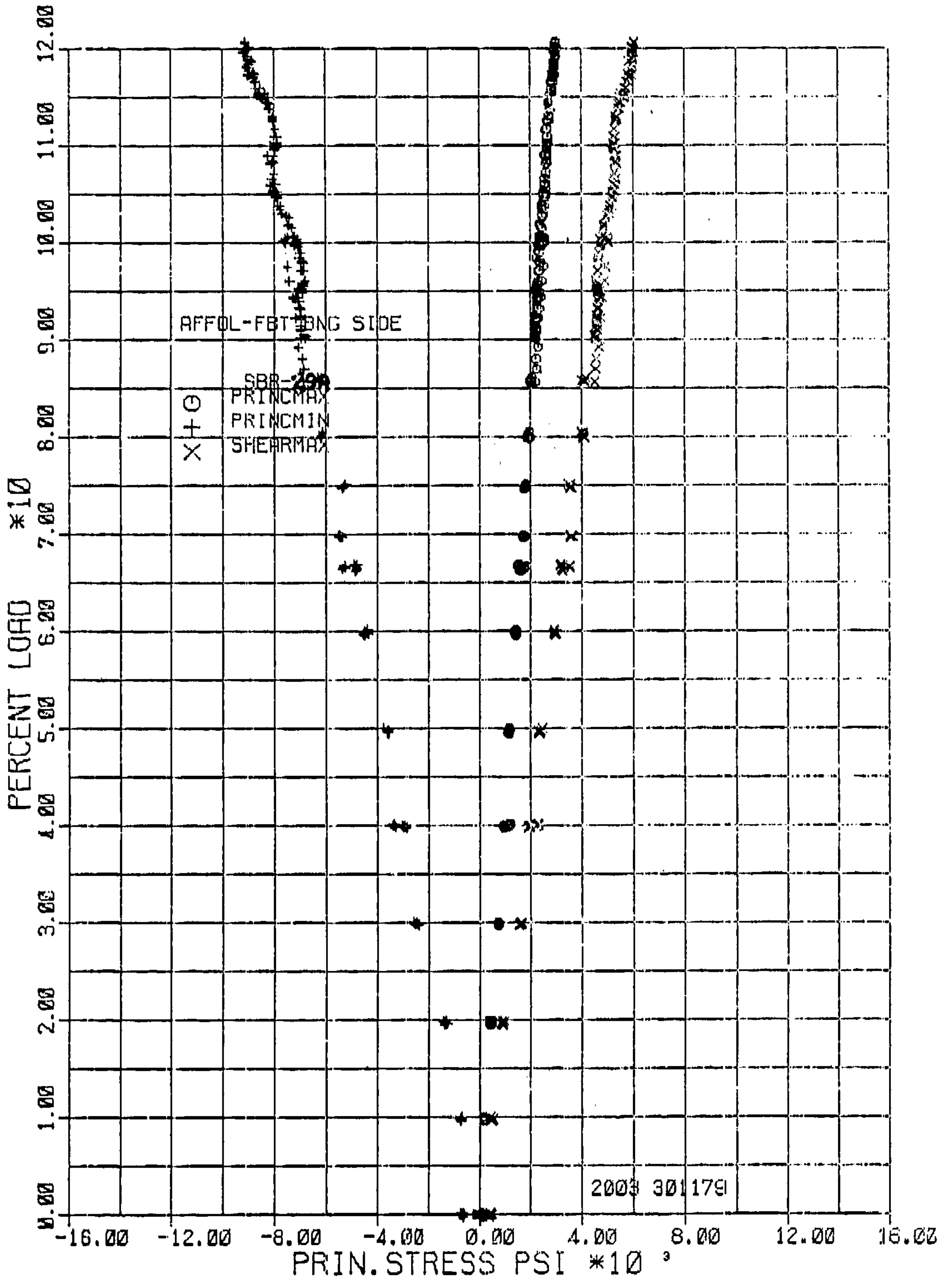
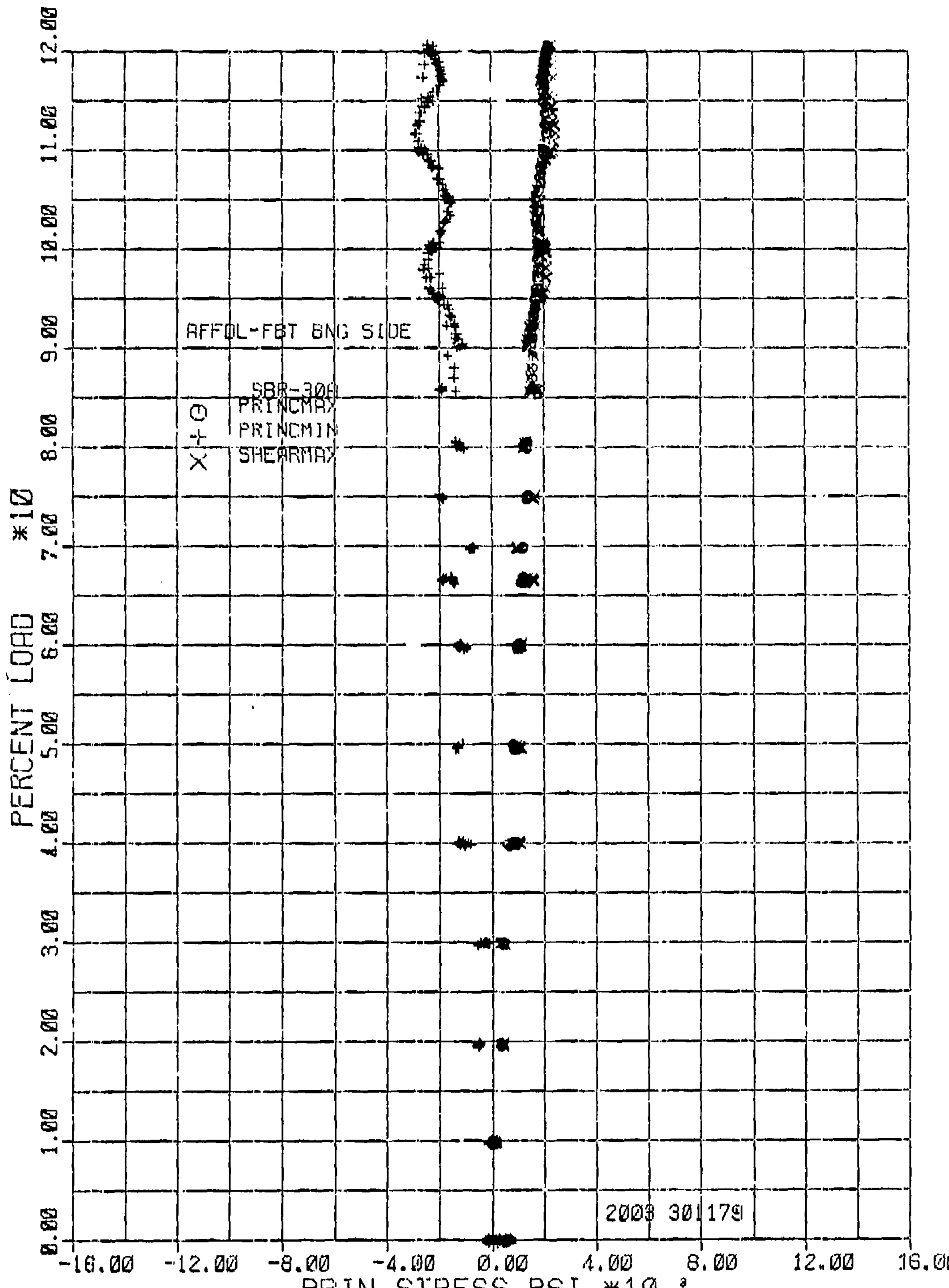


Table C-48. Bulkhead Strain Gage R30 Boeing Side Load Landing



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